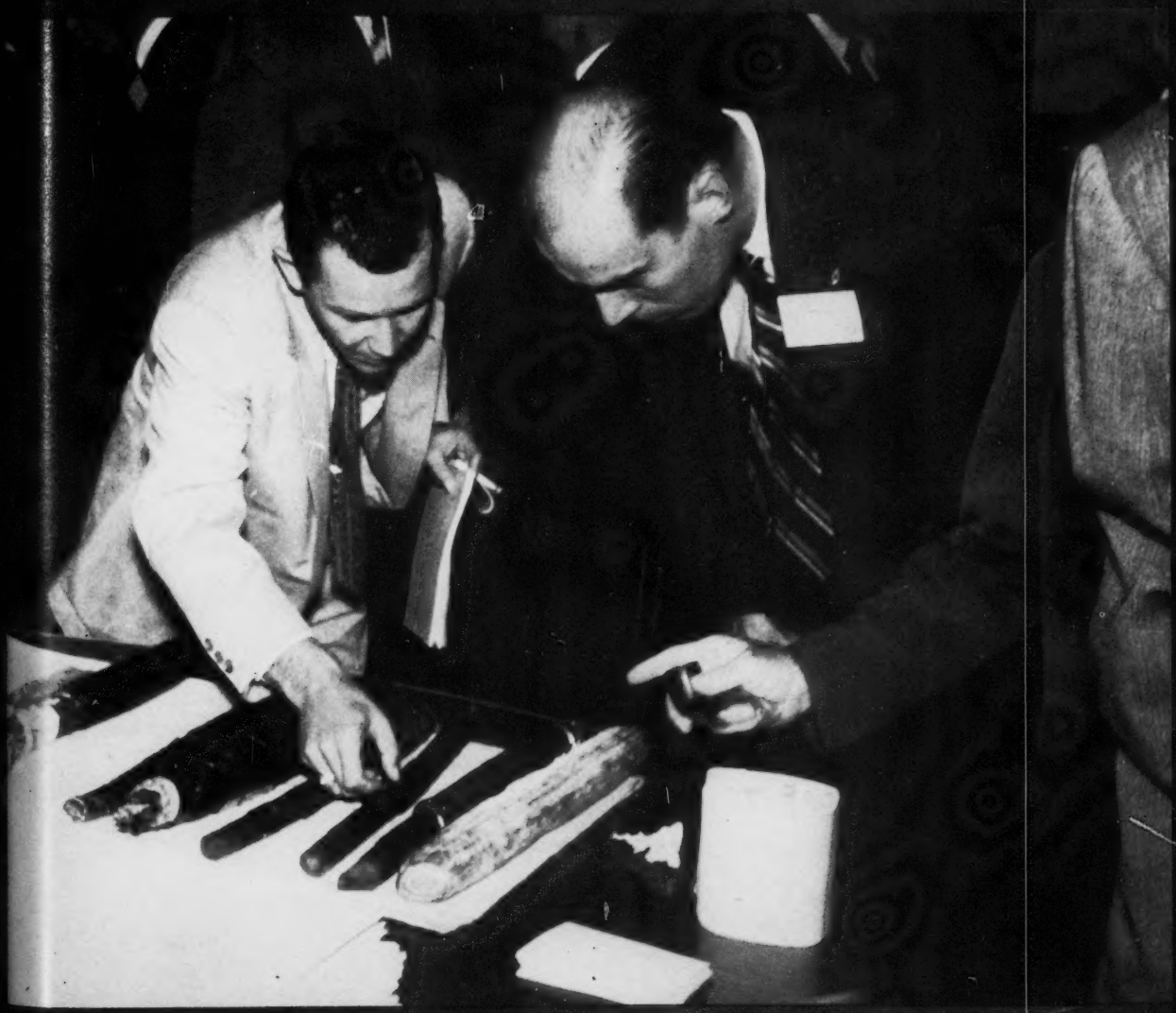
Corrosion

Official Publication
NATIONAL ASSOCIATION OF CORROSION ENGINEERS



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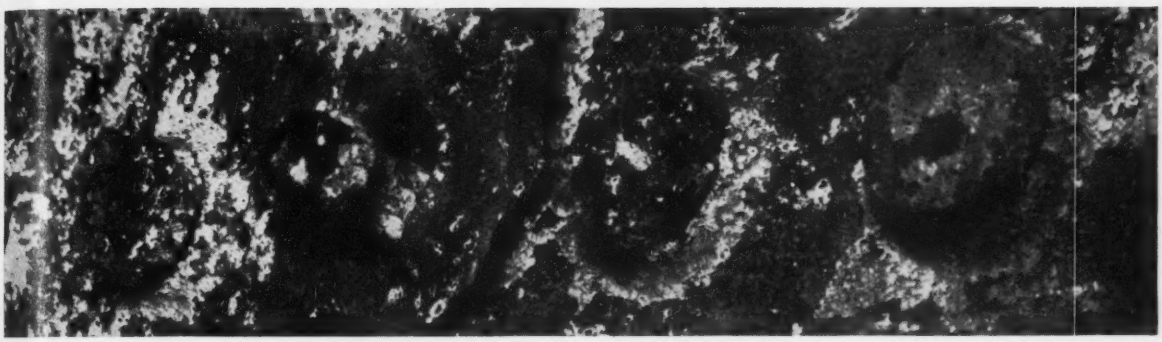

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THIS MONTH'S COVER—Engineers attending the Utilities Industry Symposium during the South Central Region Meeting at Houston October 18-21 are shown examining specimens of corroded lead-sheathed cable. NACE technical committees interested in problems connected with corrosion of lead cable sheaths have developed much valuable information during 1955.

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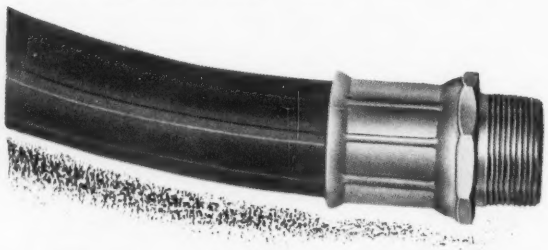

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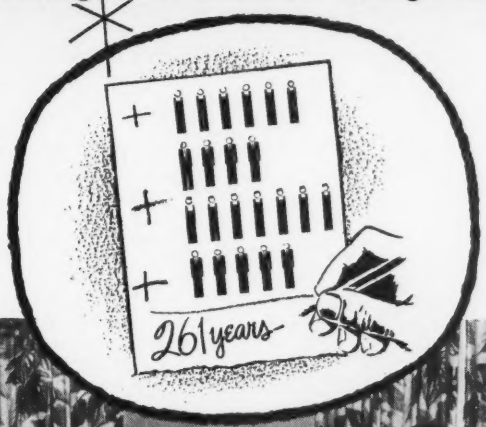

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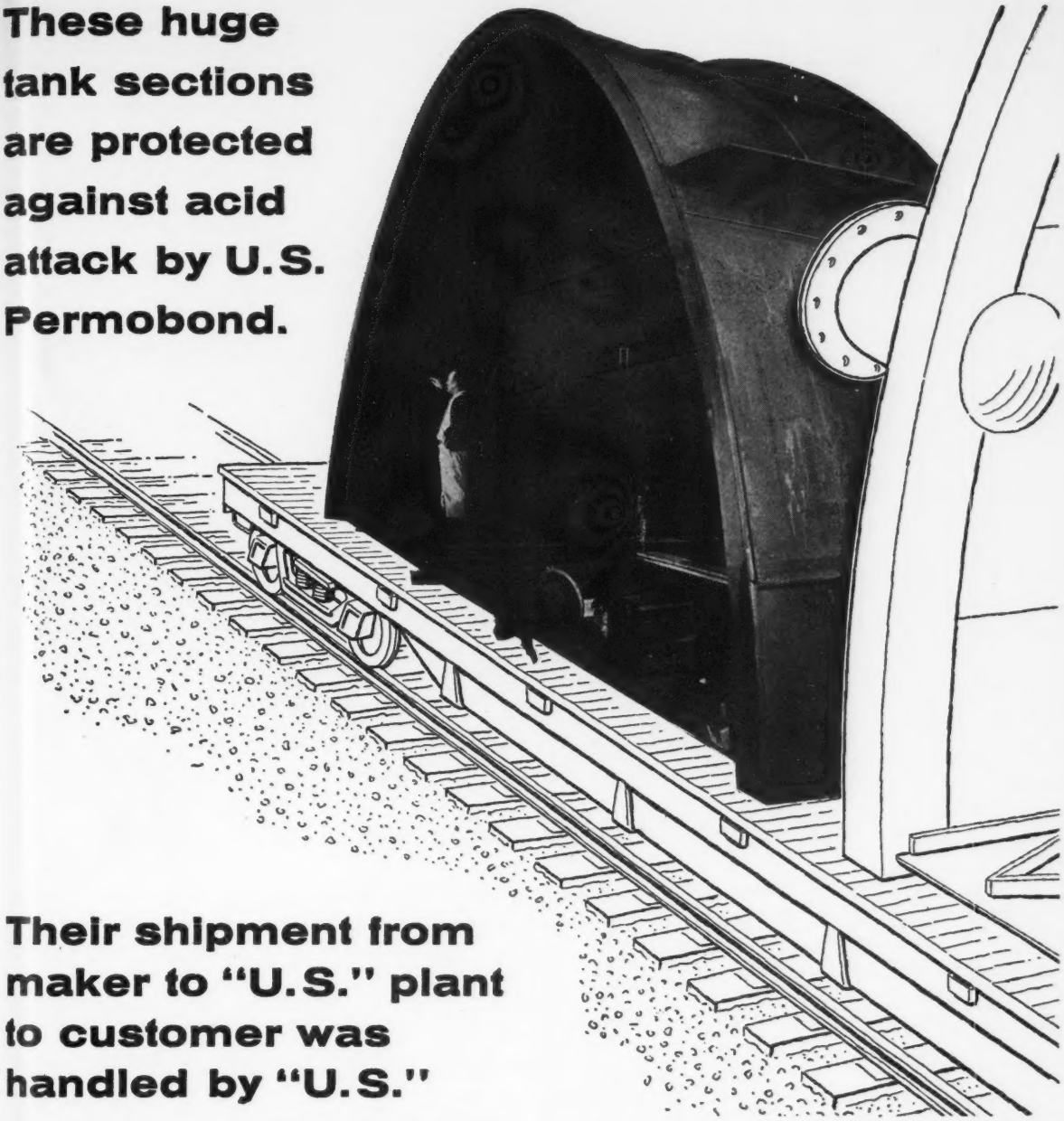

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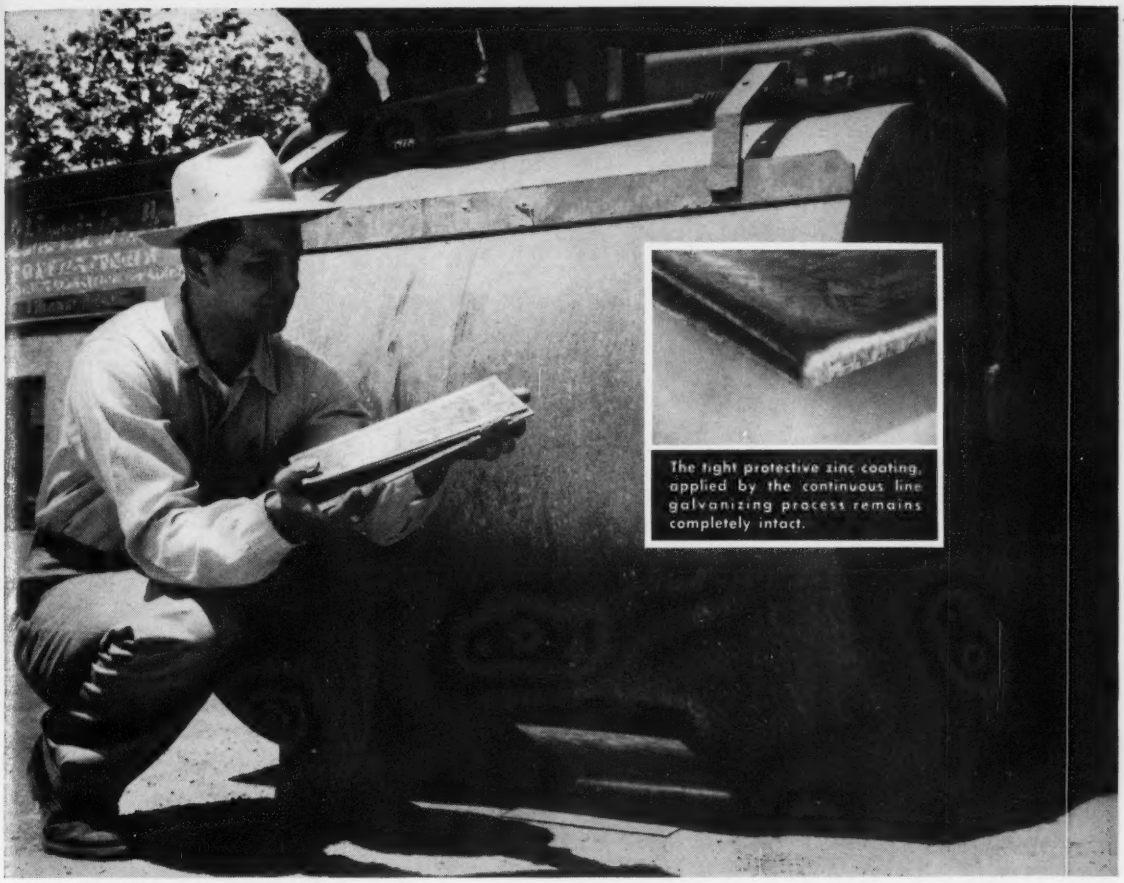
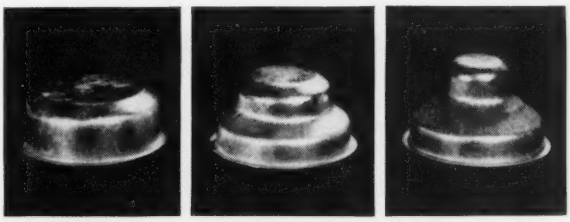
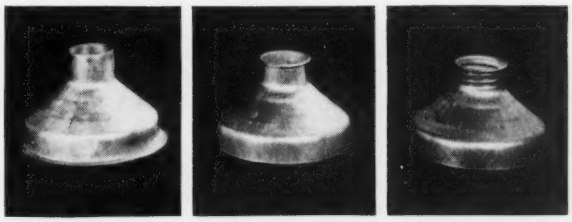
(Continued on Page 10)



THE SHAPE OF THINGS TO COME



AN EXAMPLE: This sprinkling can rosette was formerly made of black plate and then electroplated to provide the necessary rust-proofing; it is now produced from flat, galvanized stock in six operations without chipping, cracking, peeling or flaking of the protective zinc coating.



Photos of rosette, courtesy WHEELING STEEL CORP.

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Copies of back issues of Volume 11, January-December, 1955 are available except July. Persons who customarily bind all or parts of Corrosion and who lack issues to make the volume complete may get back copies at the following prices per copy, postpaid, remittance in advance: NACE members, 50 cents; Non-members, $1. An additional charge of 65 cents per package is made for mailings to addresses outside the United States, Canada and Mexico.

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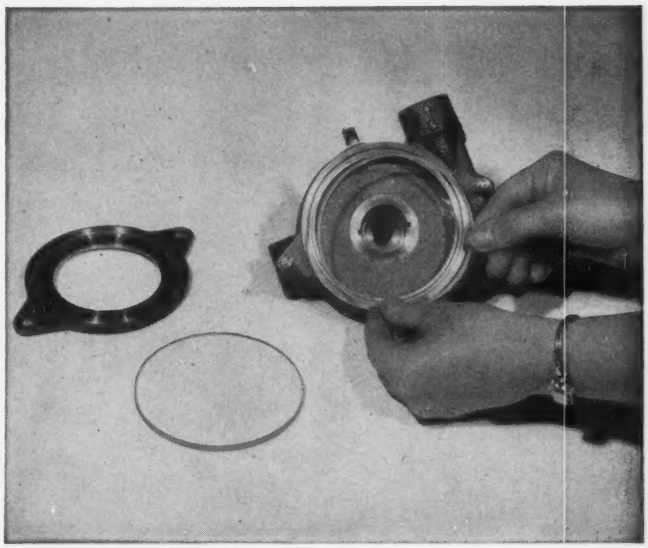

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(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

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Corrosion

OFFICIAL MONTHLY PUBLICATION

National Association of Corrosion Engineers

An Association of Individuals and Organizations Concerned with Control of Corrosion

1061 M & M Building Houston 2, Texas

Vol. 11 DECEMBER, 1955 No. 12

Topic of the Month

Stress Corrosion Cracking Of a Gold Wedding Ring

By FRED M. REINHART*

Abstract

A low karat gold alloy wedding ring that had been buried in a garden was unearthed recently and found to be brittle and cracked in many places. The cracks were identified as having been caused by stress corrosion. This condition probably resulted from the presence of residual internal stresses which were combined either with perspiration of the wearer or with the fertilizer used in the garden, or both.

MUCH has been written about the caustic remarks that sometimes are encountered during the course of married life but it is indeed a rarity to find a case where such corrosive conditions are transferred to the marriage symbol of the spouse. While a garden was being dug early this spring a wedding ring was turned up which was very brittle and contained many stress corrosion cracks.

The largest cracks originated at the ends of a rectangular embossed design on the inside surface, and extended nearly to the edges of the ring at angles of from 30 to 60 degrees. (See Figure 1.)

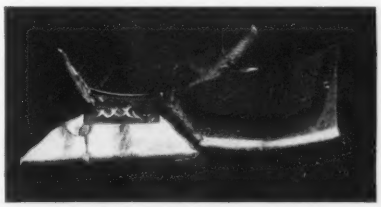

Figure 1—A portion of the cracked low karat gold wedding ring. Cracks extend from the rectangular embossed area to the outer edges at angles from 30 to 60 degrees. 2X.

Branching Cracks

Microscopic examination at 500 magnifications of polished and polished and etched sections from the upper piece shown in Figure 1 showed the presence of numerous branching cracks typical of stress corrosion cracks. These cracks were both intergranular and transgranular in nature. (See Figure 2.)

The chemical composition as determined by spectrochemical analysis was as follows:

Metal	Percent by Weight
Gold	Balance
Copper	43.5
Silver	12.3
Nickel	<0.1
Zinc	5.2

The ring was made of a low karat gold alloy. At least one failure of an alloy of similar chemical composition by stress corrosion cracking in another form, i.e., spectacle frames, has been reported in the literature.[1]

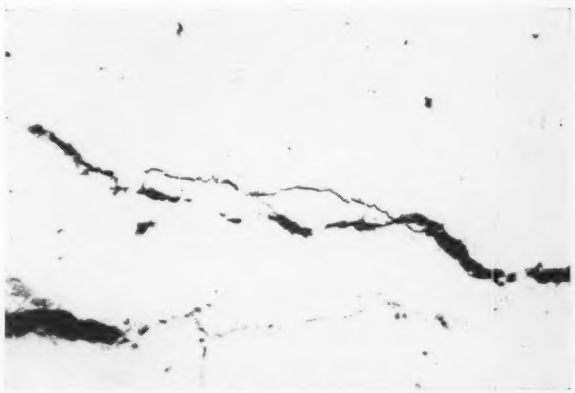

Figure 2—Branching stress corrosion cracks typical of those present throughout the ring. Unetched. 285X.

Internal Residual Stresses

The fact that the largest cracks originated at the countersunk embossed area on the inside surface of

* National Bureau of Standards, Washington, D. C.

the ring and propagated toward the edges at from 30 to 60 degree angles point to high internal residual stresses in these areas.

It is known that perspiration together with internal stresses has caused stress corrosion failures in low karat gold. The ring, obviously, was rather old and if the wearer were prone to excessive perspiration the ring could have been cracked before being lost.

On the other hand if the ring had been buried for a number of years in a much fertilized plot of ground, the ammonia, nitrites, nitrates and the traces of chlorides could either have been the corroding medium or could have been responsible for the propagation of existing cracks.

Reference

1. J. L. Christie. A Case of Season Cracking in Low Karat Gold. Symposium on Stress Corrosion Cracking of Metals, 1944, page 485.

TECHNICAL PAPERS ON CORROSION WELCOMED

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

504t

Sodium Sulfate in Gas Turbines*

By EDWARD L. SIMONS, GEORGE V. BROWNING, and H. A. LIEBHAFSKY

Introduction

SODIUM SULFATE has been recognized for more than ten years as an undesirable constituent of ash formed in the operation of conventional power plants. The role of alkali sulfates in the fire-side corrosion of wall tubes in boilers was first described in detail by Corey, Cross and Reid[1,2] who observed attack on low-carbon steels at temperatures no higher than 400-500 C.

In gas turbines burning residual fuels, sodium sulfate formation assumes new importance because ash can deposit directly on the working surfaces. These deposits have physical effects that modify gas flow so as to reduce efficiency; they also can have chemical effects, of which attack of the turbine alloy is the most important.

Other distinguishing features of gas turbine operation are the higher operating temperatures (800 C and above), and the use of high-temperature, oxidation-resistant alloys as materials of construction. Although one scarcely would expect sodium sulfate itself to attack vigorously a high-temperature alloy, there is always the possibility that some reducing agent—perhaps the alloy itself—will react with this salt to produce a small amount of lower-valent sulfur. Such sulfur might be more reactive than sodium sulfate, and hence a likely source of trouble.

Petroleum residuals, (the Bunker C fuels), while desirable because of low cost, do carry most of the inorganic impurities originally present in all of the parent crude. Often these impurities are augmented, as by contamination with sea water when the fuel is shipped by tanker. Of course, as Sykes and Shirley have noted,[3] the fuel as burned need not contain sodium sulfate for this salt to appear in the ash. Sodium sulfate can be formed during combustion in reactions analogous to that written in simplified form as:

$$2\,NaCl + (-S) + 2(-H) + 2O_2 = Na_2SO_4 + 2\,HCl \quad (1$$

In equation (1, —S and —H represent these elements as combined in the fuel. Obviously, the sodium salt of any acid more volatile than sulfuric could replace sodium chloride in equation (1. In practice, this means that any sodium compound (other than the sulfate) present in the fuel will be changed to sodium sulfate. So long as the fuel has a high sulfur content, as most residuals do, the amount of sodium sulfate in the ash is likely to be limited only by the total sodium content of the fuel.[4]

This paper is a record and interpretation of exploratory work done in the Research Laboratory. It extends observations made elsewhere in the Gen-

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Abstract

Sodium sulfate forms when residual fuels are burned in gas turbines. Its presence in the deposits which may appear on the working surfaces has undesirable physical and chemical effects. The physical effects are discussed in terms of sintering and melting. The chemical effects considered are the various possible corrosion reactions. Although all of these reactions are complex, simplified mechanisms for them are proposed, which are consistent with the experimental results and with general experience.

In particular, the violent destruction of a high temperature alloy by sodium sulfate in large excess is attributed to the triggering of an autocatalytic reaction involving this salt. Even with thin films of sodium sulfate, enhanced oxidation is observed when the atmosphere is alternately reducing and oxidizing. The following mechanism is suggested for this enhancement. Lower-valent sulfur produced in a reducing environment leads to the formation of a liquid metal-metal sulfide eutectic, which penetrates the alloy. The metal dissolved in this eutectic is more rapidly oxidized by atmospheric oxygen than is the sulfur-free alloy. Sodium sulfate itself appears to be innocuous so long as all lower-valent sulfur is absent.

Because sodium sulfate will be formed from any sodium compound present in residual fuels, the General Electric Gas Turbine Department has undertaken large-scale measures to remove sodium compounds from the fuels before combustion. Results so far are promising.

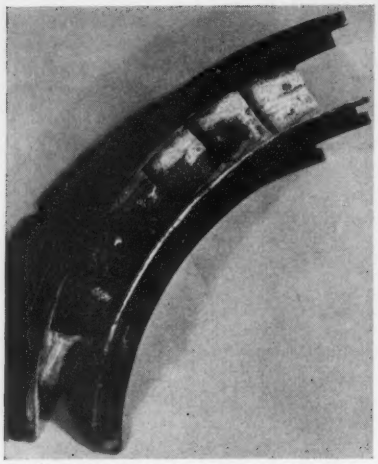

Figure 1—Section of first-stage nozzle from 5000 kilowatt General Electric gas turbine after 800 hours of operation on Bunker C fuel.

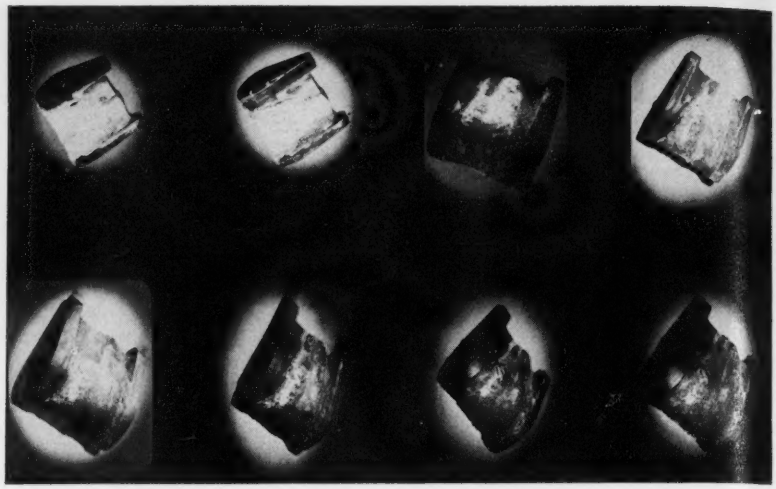

Figure 4—Effect of successive 30-minute exposures at various temperatures on first-stage nozzle partition shown in Figure 3. Upper row (left to right: Partition as received (Figure 3), 700, 750, 800 C; lower row (left to right): 850, 900, 950, 1000 C.

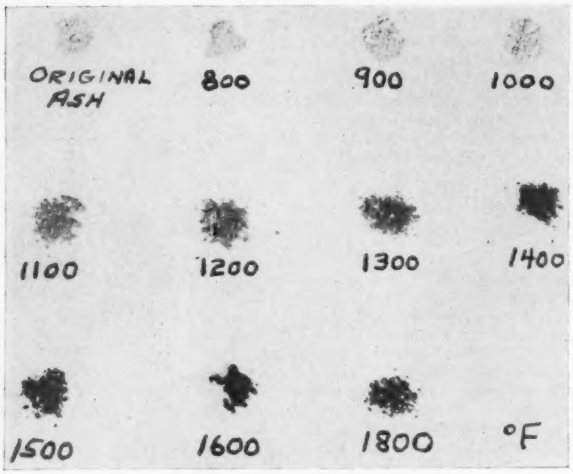

Figure 2—Effect of temperature on gas turbine ash deposit.

Figure 3—First stage nozzle partition as removed from section shown in Figure 1.

eral Electric Company, notably by Satz[5*] and by Buckland, Gardiner and Sanders.[6**]

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Physical Effects

Because of its low melting point (883 C), sodium sulfate can greatly modify the physical properties of an ash. Thus the presence of sodium sulfate has a direct bearing on how readily the ash deposits on a turbine surface, how tightly it adheres, how long it remains, how thick it becomes, and what kind of surface it presents to the flowing gas.[7] An example to illustrate these points is given below, but conclusions based upon it must be applied with care because a number of uncertain variables are involved.

Field Experience

In the spring of 1952, parts from a 5000 kilowatt General Electric gas turbine that had run for 800 hours on a Bunker C fuel were examined. The photograph (Figure 1) of a section of the first-stage nozzle shows striking differences in the appearance of the deposit at different locations. The light-colored ash is a fine, easily wiped off powder. The dark deposit, on the other hand, is hard and so tightly held that it can be removed only by vigorous chopping or abrading.

Qualitative spectrographic analysis revealed no differences between the light and dark deposits. Chemical analysis showed that both were composed principally of sodium and calcium sulfates with a higher ratio of sodium to calcium in the dark material. Color was traceable to metallic oxides (mainly those of vanadium, iron, nickel, and chromium) present as minor constituents. Differences in chemical composition clearly could not account for the differences in the physical characteristics of the light and the dark ashes.

Simple tests proved that the light and dark areas must have been at different temperatures in the turbine. Small samples of the light ash on platinum foil were heated in a furnace at various temperatures (see Figure 2). The ash darkened progressively with increases in the temperature to which it had been

heated, and sintering began at 870 C. Ashes heated above that temperature were changed from soft, loose powders to hard cakes that adhered strongly to the platinum. This behavior was demonstrated on the nozzle partition itself (see Figures 3, 4 and 5).

It is clear, then, that heating the ash greatly changes its physical characteristics. In addition to affecting operating efficiency, these changes are certain to influence any reaction involving the ash and the alloy; in other words, physical and chemical effects may interact. The relationship between color of ash and temperature of heating, which is clear from Figures 2 and 4, can be used as a rough but valuable guide to estimate the distribution of maximum temperatures in the first stage of the turbine during operation.

Evidence from the Phase Rule

Inasmuch as sodium sulfate melts at a much lower temperature than any other major constituent of the ash, it is logical to attribute to sodium sulfate the physical changes produced in the ash on heating. Nevertheless, it is worth while to confirm this point of view by a brief examination of the phase diagram for the sodium sulfate—calcium sulfate system. Figure 6 is a schematic representation of this diagram and is based upon the data of Müller[8] and of Calcagni and Mancini[9] as interpreted by Bredig.[10] There is a general agreement on the existence of the eutectic at 913-917 C, the principal feature of interest in the present connection.

In Figure 6 the upper and lower curves (ABE and ABC) represent solid solutions and denote the compositions of the liquid and solid phases that can coexist at equilibrium. At 949 C both phases have the same composition, 22.5 mole percent $CaSO_4$. The curve ED represents the effect of Na_2SO_4 upon the freezing point of $CaSO_4$. The eutectic point of 40 mole percent $CaSO_4$ and 913 C marks the coexistence of a liquid of this composition with pure solid $CaSO_4$ and the limiting $CaSO_4$-rich solid solution (33 percent $CaSO_4$).

In terms of the melting behavior of Na_2SO_4-$CaSO_4$ mixtures, the phase diagram has the following significance:

1. The melting point of any mixture in the Na_2SO_4-rich solid-solution region is given by the appropriate composition intercept on curve ABC. The melting point of such mixtures can vary therefore from 883 to 949 C.
2. Any $CaSO_4$-rich mixture will begin to melt at the eutectic temperature of 913 C, to form a liquid of the eutectic composition, 40 percent $CaSO_4$. The richer the mixture in $CaSO_4$, the smaller the relative portion that melts at this temperature, but in all cases some liquid phase will form. For a given mixture, the higher the temperature (above 913 C), the greater the relative extent of melting; melting is complete at the temperature marking the appropriate composition intercept on curve ED.

It was shown experimentally that the behavior on melting of sodium sulfate-calcium sulfate mixtures was in accord with the phase diagram and unaffected by the presence of a few percent of ferric oxide.

The "original ash" of Figure 2 contained 84.3 percent $CaSO_4$ and 2.8 percent Na_2SO_4, both percentages by weight. If minor constituents are disregarded, the ash corresponds to a composition of 97 mole percent $CaSO_4$ in Figure 6. Even such a mixture, although its freezing point lies well above 1300 C, should show melting at the eutectic temperature of 913 C. But it should not show melting to an extent exceeding 5 percent by weight.

A sample of this "original ash" was heated for 10 minutes on platinum at 925 C. It was evident from the appearance of the powder after heating and from its tight bonding to the platinum foil that the particles were cemented together. Microscopic examination showed the presence of what had been a molten phase at 925 C. The presence of a small percentage of sodium sulfate thus had a profound influence on the physical properties of the ash.

The colored constituents of the ash, particularly iron oxide, not only grow darker in color as they are heated, but also are insoluble in the molten phase

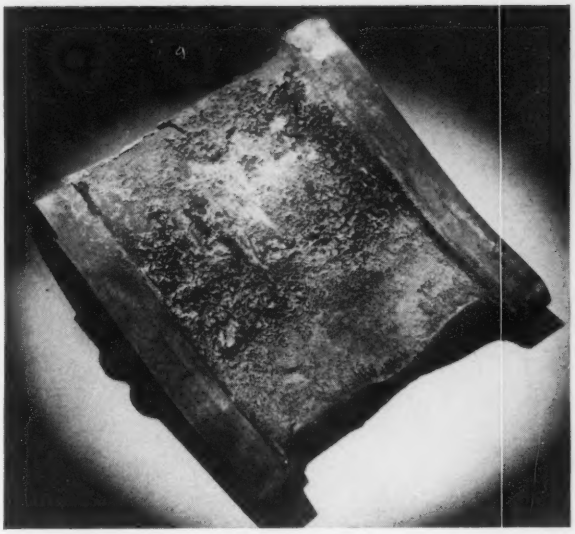

Figure 5—First-stage nozzle partition (concave side) after 900 C exposure described in Figure 4.

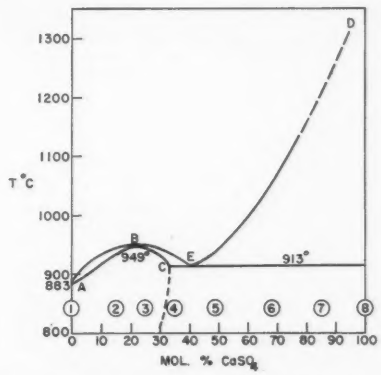

Figure 6—Freezing point—composition diagram for Na_2SO_4 system. Circled numbers represent compositions of synthetic mixtures.

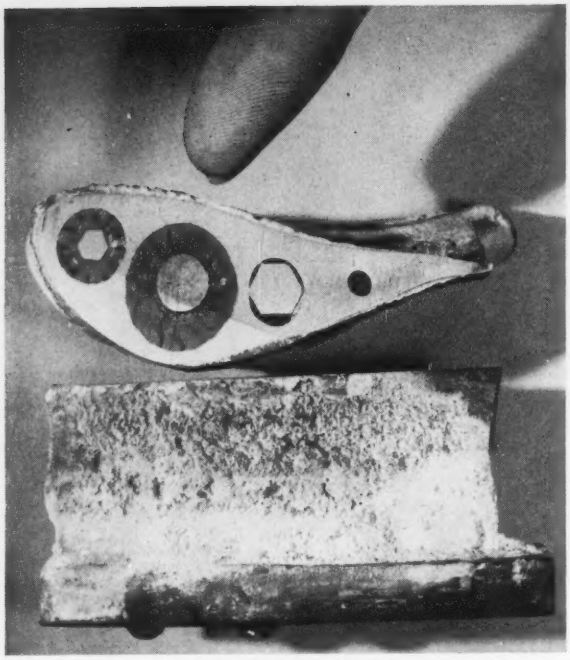

Figure 7—Stratification of deposit on first-stage nozzle partition, showing concentration of colored oxides at outer surface of sodium sulfate-calcium sulfate layer.

and segregate at its surface. In Figure 7 which shows a cross section through a nozzle partition, the dark ash deposit is actually dark only at the upper surface where the colored oixdes have concentrated. The underlying layer is a mixture of the white sulfates of sodium and calcium. This segregation also has been noted by Satz[5] in fire-side boiler-tube deposits formed in the combustion of residual fuel.

Thus the melting behavior of sodium sulfate-calcium sulfate mixtures and the insolubility of the colored metal oxides in the resulting liquid phase combine to explain how increasing the temperature converted the light, homogeneous fine powder into a dark, hard and heterogeneous scale. It is worth repeating that a very small amount of sodium sulfate was sufficient to make possible this great change in physical properties.

Chemical Effects

The first intimation that sodium sulfate could be a factor in the corrosion of high-temperature alloys came to the authors from the work of L. H. Satz,[5] who suggested that the sulfur present in the sulfide inclusions near the fire-side surface of mercury-boiler tubes was derived from sodium sulfate. Satz' findings were reinforced by the work of Sykes and Shirley;[3] also by the results of numerous "crucible tests" carried out by Buckland, Gardiner and Sanders[6] in which various alloy steels, including Type 310 (25 percent Cr, 20 percent Ni), were heated in contact with different mixtures that resembled deposits to be expected in gas turbines burning residual fuels.

The results of crucible tests carried out with sodium sulfate often were erratic; in most cases no attack was observed but in others there was complete destruction. In general, rapid attack occurred when the sodium sulfate deliberately was contaminated with carbon or when the metal surface was contaminated by handling.

The fact that sodium sulfate-carbon mixtures were found to be corrosive is not surprising. In such a mixture, reduction of sodium sulfate by carbon should occur, and the sensitivity of high-temperature alloys to sulfur and some of its compounds (sulfates excepted) is well known. Kubaschewski and von Goldbeck[11] recently have summarized this situation. According to Sykes and Shirley,[3] pure sodium sulfate is innocuous toward heat-resisting steels, although rapid oxidation can occur when the sulfate-metal system is contaminated with sodium chloride or sulfur dioxide.

Nothing found in the earlier literature points to sodium sulfate itself as a destroyer of high-temperature alloys. In 1848, d'Heureuse[12] remarked that the reactions of metals with various sulfates were little known, and that his investigation of these reactions of iron showed them to be unexpectedly complex. Succeeding years have not altered the validity of this viewpoint. In Rabald,[13] nickel is recommended as the best material for the fusion of sodium sulfate. Chrome-nickel alloys are described there as not particularly resistant though used in practice, with attack of the alloy at 1000 C reaching possibly 100 grams/square meter/day. Bunzel and Kohlmeyer[14] found that iron began to react with sodium sulfate at 1100 C, but that nickel and cobalt remained inert until a temperature of approximately 1500 C was reached. The contrast of these observations with those of Buckland, Gardiner and Sanders[6] is obvious.

The three kinds of exploratory experiments described below were carried out in the hope of extending the understanding of this complex and confused situation.

Crucible Tests

In experiments patterned after those of Buckland, Gardiner and Sanders,[6] clean pieces of Type 310 stainless steel (2.5 x 0.6 x 0.3 cm; weight, 3.8 grams) were placed upright in 22 grams of anhydrous sodium sulfate contained in 30 cc porcelain crucibles so that about 0.8 cm projected above the salt. The crucibles were then heated in air at 950 C in a muffle furnace for varying times. By and large, the conclusions of Reference 6 were confirmed. The results of three striking experiments are shown in Figure 8.

In the first experiment (Figure 8, upper right), heating for three days yielded a yellowish salt cake and a superficially attacked metal strip. In addition, there was a band of finely divided dark red particles at the upper periphery of the cake.

As Figure 8 shows, the metal was completely destroyed in the other two experiments, even though one of these lasted only a few hours. The salt cakes there were black, owing no doubt to dispersed metallic oxides.

It appears that the first three-day experiment may be regarded as a preliminary stage of the other two,

one of which was much shorter. This indicates attack of high-temperature alloys by a large excess of sodium sulfate to be sporadic, unpredictable, and potentially violent. General experience bears this out.

The following features seem to characterize the violent attack: 1) The attack needs to be triggered, but once under way is extremely rapid. 2) The attack involves reactive sulfur species of valences between +6 and —2 that are produced by the reduction of sodium sulfate. (Note the yellow color of the salt cake and the red particles formed in the three-day experiment reported above.) 3) Mechanical disruption of the alloy as a consequence of penetration along grain boundaries, though not observed, seems plausible in view of evidence to be presented later. (See also Reference 11.)

It is desirable to suggest a mechanism, however oversimplified, for this complex reaction. The attack undoubtedly is accelerated both by the destruction of protective oxide films and by an increase in temperature owing to the progress of exothermic reactions. In addition, however, the violence of the attack leads one to believe that it involves an autocatalytic reaction in which the lower valent sulfur participates directly. The following assumptions will be made:

1. The initial triggering phase involves the reduction of sodium sulfate by a reducing agent, R, to a single reactive sulfur species, S.
2. This lower-valent sulfur species, S, reacts with Type 310 steel (considered as a metal M) to form only one sulfide, MS.
3. Sodium sulfate is the principal oxidizing agent initially present in the system.

The suggested mechanism may be written in two stages as follows:

Triggering Phase $Na_2SO_4 + 3R = Na_2O + 3RO + S$ (1

(Sporadic and unpredictable) $M + S = MS$ (2

Autocatalytic Destruction

$Na_2SO_4 + 3MS = 4S + 3MO + Na_2O$ (3

(Rapid and violent) $4M + 4S = 4MS$ (4

Many other reactions could of course be written, and it is not likely that any simple set of such reactions will describe adequately all phases of the process. Autocatalysis results because more than one S is produced per sodium sulfate molecule in Reaction 3.

Possible participation of atmospheric oxygen has been neglected above because the destruction of metal is so rapid and the excess of sodium sulfate so great.

Controlled Triggering

A logical step to take next is to bring the triggering phase under control. If the proposed mechanism is correct, electrolysis should be a good way of doing this, for reduction of sodium sulfate is to be expected at a cathode. With a cathode of Type 310 steel, the autocatalytic phase should begin soon after the onset of electrolysis, and subsequent destruction of the cathode by chemical action should be rapid. This process could be represented by:

Triggering by Electrolysis

$Na_2SO_4 + 8e = S^= + 3O^= + Na_2O$ (5

followed by

$Na_2SO_4 + S^= + 3M = Na_2O + 2S + 3MO$ (6

Autocatalytic Destruction (as in Equations 3 and 4)

These expectations were decisively realized. Two electrodes (each 0.3 x 1.0 x 3.5 cm) of Type 310 steel were partially immersed in molten sodium sulfate contained in a 20 cc porcelain crucible. With 45 volts d.c. across the electrodes, a current of 0.1 amp flowed. Reddish-brown streamers were generated rapidly at the cathode, and this electrode became spotted with flocculent material. The amount

Figure 8—Effect of sodium sulfate on Type 310 steel at 950 C in muffle furnace. Upper left: Crucible at start of experiment. Upper right: First three-day experiment. Slight attack. Lower right: Second three-day experiment. Complete destruction of sample. Lower left: Complete destruction of sample within a few hours.

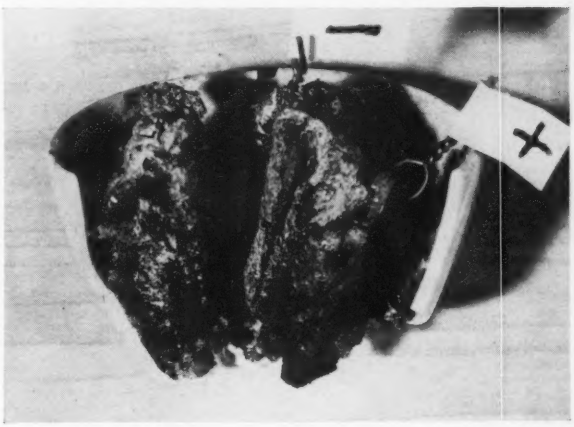

Figure 9—Cross section of crucible showing extensive destruction of Type 310 cathode after one-hour electrolysis at 45 volts in molten sodium sulfate. Note that attack on the anode was much less severe.

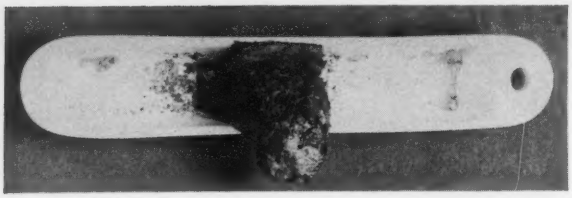

Figure 10—Attack of oxygen on Type 310 steel (2.5 hours at 900 C) after prior exposure to hydrogen sulfide for one hour at 900 C.

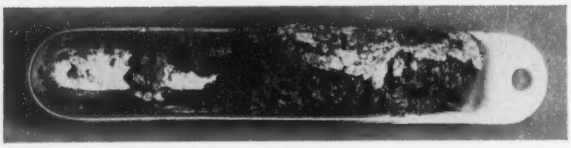

Figure 11—Complete destruction of strip of Type 310 steel by sodium sulfate after successive 1.5-hour exposures to hydrogen and oxygen at 900 C.

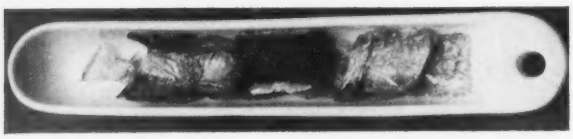

Figure 12—Type 310 steel and sodium sulfate after six-hour exposure at 900 C.

of such material increased steadily until it encompassed the cathode to a distance of about 0.3 cm. Then the temperature of the cathode and surroundings began to rise, and after about one hour very little of this electrode remained. The cross section of the crucible at the end of the experiment is shown in Figure 9.

Auxiliary experiments gave the following results: 1) No attack was observed when the circuit was open. 2) Pronounced attack of an anode did not occur except as induced by reaction products originating near the cathode. 3) The reddish-brown streamers formed at a platinum cathode also. 4) After a brief period of electrolysis, a cathode of Type 310 steel had a soapy feeling and reacted with water to evolve hydrogen sulfide.

If the reddish-brown streamers contain the reactive sulfur species represented as S in the mechanisms written above—and this is plausible at the very least—then the electrolytic experiments strongly support the kind of mechanism assumed above. It is not often that a cathode is almost destroyed while an anode of the same metal escapes attack.

Several attempts at chemical triggering provided further corroboration.

1. In a nitrogen atmosphere, Type 310 steel strips were immersed for 15 minutes in a bath of molten sodium hydroxide containing a small amount of sodium sulfide. The strips thus pre-treated, after being washed with water and dried, behaved upon immersion in molten sodium sulfate as did cathodes of the same alloy. They rapidly developed a surface coating of flocculent material and were destroyed completely in 30 minutes.
2. A strip of Type 310 steel was exposed for one hour to hydrogen sulfide at 700 C, then partially immersed in sodium sulfate, and heated at 900 C in oxygen for 2.5 hours. At the end of this period, most of the sample remained, but it then supported a black, porous tower of corrosion products ten times the original thickness of metal (Figure 10).
3. A strip of Type 310 steel was placed in a porcelain boat half filled with sodium sulfate, and exposed to a stream of hydrogen at 900 C for 1.5 hours. This

TABLE 1—Description of Experiments with Thin Coatings of Sodium Sulfate

EXPERIMENT 1
Initial alloy weight: 0.7973g. Initial sodium sulfate weight: 0.0448g.[1]

Approximate Time (Hrs.)	Experimental Conditions	Observations	Suggested Conclusions
0—1.5	In air at 900 C.	Weight increase negligible.	Molten Na_2SO_4 innocuous.
1.6—2.2	H_2,[2] then air at 600 C.	Weight change negligible.	No reduction of Na_2SO_4. Na_2SO_4 innocuous.
2.3—3.7	H_2, then air at 700 C.	Weight change negligible.	No reduction of Na_2SO_4. Na_2SO_4 innocuous.
4.2—4.6	H_2, then air at 750 C.	Weight decreased, then recovered.	Na_2SO_4 reduced and completely reformed.
4.6—4.7	In air at 800 C.	Weight virtually constant.	Na_2SO_4 innocuous.
4.7—4.8	H_2, then air at 800 C.	Weight decreased, then increased.	Na_2SO_4 reduced and reformed.
4.8—6.5	In air at 800 C.	Weight increased continuously.	Enhanced oxidation.[3]

EXPERIMENT 2
Initial sample weight: 0.8042g. Initial sodium sulfate weight: 0.0305g.[1]

Approximate Time (Hrs.)	Experimental Conditions	Observations	Suggested Conclusions
0.0—2.2	In air at 900 C.	Weight increase negligible.	Molten Na_2SO_4 innocuous.
2.2—3.1	H_2, N_2, then air at 900 C.	Weight decreased, then increased.	Na_2SO_4 reduced and reformed.
3.1—5.1	In air at 900 C.	Weight increases rapidly at decreasing rate.	Enhanced oxidation.[3]
5.1—22.3	In air at 900 C.	Weight increases continuously.	Moderately enhanced oxidation.
22.3—26.6	Second reduction—oxidation cycle.	About as in first cycle.	Effect less marked than in first cycle.

EXPERIMENT 3
Initial alloy weight: 0.8203g. Initial sodium sulfate weight: 0.0987g.[1]

Approximate Time (Hrs.)	Experimental Conditions	Observations	Suggested Conclusions
0.0—1.0	Air at 900 C on reactive sample.	Rapid weight gain.	Enhanced oxidation. Perhaps some oxidation of sulfur compounds.
1.0—21.6	In air at 900 C.	Weight increases continuously.	Moderately enhanced oxidation.
21.8—27.0	First reduction—oxidation cycle.	As expected.	Nothing new.
27.0—47.7	Second reduction—oxidation cycle.	As expected. Note marked weight changes.	Some reduction and reformation of metallic oxides probable.
47.7—53.0	Third reduction—oxidation cycle.	As expected.	Nothing new.

[1] Weight losses for complete conversion of Na_2SO_4 to Na_2S: 0.0202g. (Experiment 1); 0.0137g. (Experiment 2); 0.0445g. (Experiment 3).
[2] Hydrogen treatment as follows in all cases: furnace flushed with N_2, then few percent H_2 introduced into N_2.
[3] To make enhanced oxidation possible, some lower-valent sulfur must have escaped re-oxidation in previous cycle.

treatment produced a dark coating on the sample, but no extensive attack. During a subsequent exposure to oxygen at 900 C for 1.5 hours, the strip was completely destroyed, and the boat contained only a large porous clinker of oxide (Figure 11). By contrast, a sample exposed to oxygen alone for six hours at 900 C experienced no destructive attack (Figure 12).

Thin Coatings of Sodium Sulfate

Although the crucible and the controlled-triggering experiments provided dramatic evidence of the destructive potentialities of sodium sulfate for Type 310 steel, they could not present a true picture of conditions in gas turbines. The working surfaces do not operate in molten sodium sulfate, but rather become coated during operation with a layer of this salt that is thin compared to the alloy underneath. To observe the effect of thin coatings of sodium sulfate upon the oxidation of Type 310 steel, the experiments described below were performed.

Weight changes were measured on three polished and cleaned strips of Type 310 steel (1 x 0.3 x 0.3 cm) that had been coated by dipping with a thin layer of molten sodium sulfate (see Table 1).

Reddish-Brown Streamers. Contamination with reducing agents during the dipping in molten salt was a likely possibility. In fact, reddish-brown streamers, similar to those emerging from the cathode during electrolysis, sometimes were observed during the application of the sodium sulfate in thin coatings. The decision was made to test one strip (Experiment 3) that showed reddish-brown streamers during dipping (the strip probably was contaminated with lower-valent sulfur). Tests were to be made also on two strips (Experiments 1 and 2) for which there was no evidence of such contamination.

In these experiments, a coated strip was suspended with a platinum wire from one arm of an ordinary analytical balance so that it hung within a quartz tube placed inside an electrically heated furnace as shown in Figure 13. The atmosphere around the strip was changed by introducing different gases at the bottom of the tube. Experimental conditions were varied during each experiment, and the weight of the coated strip (and of the platinum wire) was recorded from time to time. The results are plotted in Figures 14, 15 and 16 and interpreted in Table 1, which serves as a guide to the figure. For the appearance of the strips after the experiments, see Figure 17.

Although, as Figures 14, 15 and 16 show, the three experiments yielded interesting information that establishes the value of the method, further work is required before a detailed treatment is warranted. Therefore, not all of the suggested conclusions in Table 1 will be discussed below.

Abrupt Dips. The abrupt dips

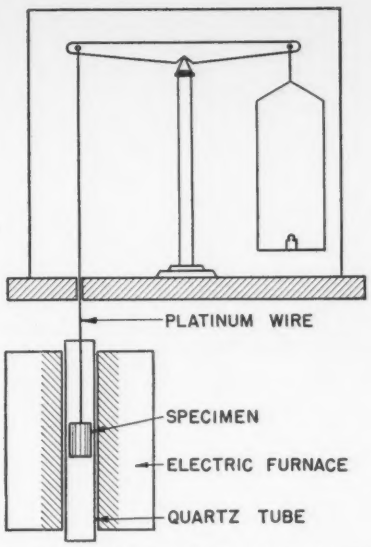

Figure 13—Schematic diagram of experimental arrangement for following weight gain during oxidation experiments.

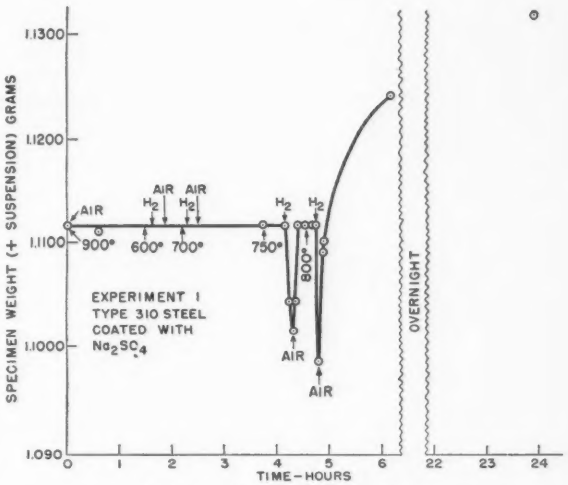

Figure 14—Experiment 1 of Table 1.

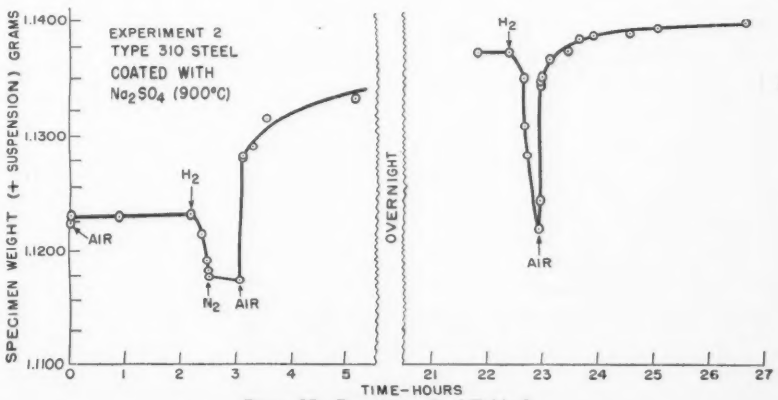

Figure 15—Experiment 2 of Table 1.

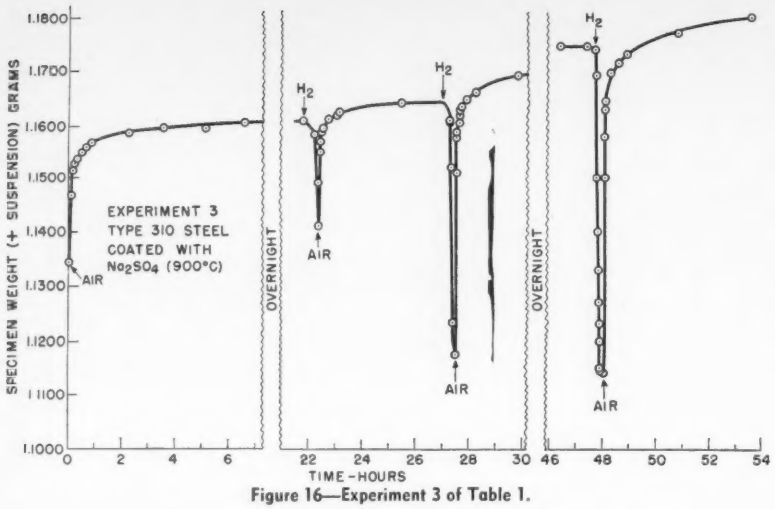

Figure 16—Experiment 3 of Table 1.

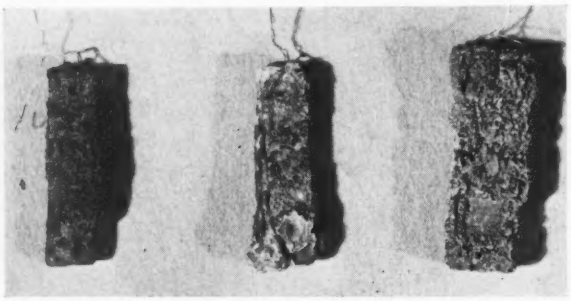

Figure 17—Type 310 samples after oxidation. Left to right: Experiments 2, 1 and 3 of Table 1.

are the most striking features of Figures 14, 15 and 16. They show how rapidly sodium sulfate is reduced and reformed, presumably in the reactions:

$$\text{Reduction:} \quad Na_2SO_4 + 4H_2 = Na_2S + 4H_2O \qquad (7$$

$$\text{Oxidation:} \quad Na_2S + 2O_2 = Na_2SO_4 \qquad (8$$

The suddenness with which these reactions start and stop is clear from Figures 14, 15 and 16; note especially the nearly horizontal line for the nitrogen atmosphere in Experiment 2. Comparison of the weight changes in these figures with the calculated values for Reactions 7 and 8 (see bottom of Table 1) shows that these reactions could have approached completion only in the second cycle of Experiment 2, and in the last two cycles of Experiment 3.

Figures 14, 15 and 16 provide convincing evidence that sodium sulfate in an oxidizing atmosphere at 900 C can be innocuous toward Type 310 stainless steel for several hours. It is entirely possible, of course, that the alloy itself is reducing sodium sulfate at an imperceptible rate; i.e., that the alloy takes the place of R in equation (1. But there is no indication that this reaction could trigger the destruction of the alloy; obviously oxygen has its best opportunity to re-oxidize traces of lower-valent sulfur when the sodium sulfate layer is thin.

Enhanced Oxidation of Alloy. As was expected, the initial behavior of the (presumably) contaminated strip in Experiment 3 differed sharply from that of the other two. Part of the rapid early weight increase may have been caused by an oxidation of lower-valent sulfur compounds, but there is no reason to believe that this could have accounted for all the increase. It is reasonable to suppose that much of this increase was due to enhanced oxidation of the alloy, and this supposition is reinforced by the similarity of the initial stages of Experiment 3 to the course of Experiment 2 when air was admitted after sodium sulfate had been reduced by hydrogen. It is reasonable further to suppose that the decreasing slope of the curve for Experiment 3 reflects a decreasing rate of oxidation owing to the formation of a protective oxide film.

The term *enhanced oxidation* will be used to describe the process in which some form of lower-valent sulfur increases the rate of atmospheric oxidation of a metal markedly above that characteristic of a clean surface in the absence of sulfur. In Figures 14, 15 and 16, enhanced oxidation appears to have occurred in each experiment when air was first brought into contact with a strip in the presence of lower-valent sulfur. On subsequent contacts, the weight changes do not point as clearly to enhanced oxidation, but this is because of the protective action of the scale then present.

Enhanced oxidation produced by lower-valent sulfur has been observed by Preece and others[15,16,17] in their extensive investigations of the scaling of mild and low-alloy steels in furnace atmospheres. In certain atmospheres the presence of sulfur dioxide led to rapid oxidation of the steels. This oxidation was accompanied by intercrystalline penetration of the metal by an iron-iron sulfide eutectic.

Skinner[18] reported a similar enhanced oxidation of high-temperature alloys in atmospheres containing small amounts of sulfurous impurity, and said: "It is apparent that acceleration of the otherwise low scaling rate is associated with preferential oxidation of the molten sulfide compound which characteristically forms in the alloy immediately inward from the advancing front of oxidation."

Explanation of Enhanced Oxidation. Thus the basic postulates in the explanation of enhanced oxidation are: 1) The metal is penetrated by a liquid metal-metal sulfide eutectic, and 2) Oxidation of these inclusions proceeds more rapidly than that of the sulfur-free alloy. The photomicrograph (Figure 18) of Sample 3 of Table 1 shows sulfide inclusions similar to those appearing in the photomicrographs of Preece and of Skinner. It already has been mentioned that such a process could lead to mechanical disintegration of an alloy under extreme conditions

when an excess of sodium sulfate is present.

The following simple mechanism is suggested for this enhanced oxidation. Several common metals form eutectics with their sulfides; nickel, for example, forms a binary eutectic that contains 21.5 percent sulfur by weight and melts at the exceptionally low temperature[19] of 644 C. Let M•MS be an eutectic (or eutectics) formed by a Type 310 steel, and assume that the liquid eutectic can penetrate otherwise protective films and move rapidly along grain boundaries. Metal thus dissolved in an eutectic would be highly reactive toward oxygen, not only because it is dissolved but also because truly protective films seldom form on a liquid. The following simple equations therefore may be used to represent the enhanced oxidation:

$$\text{Solution of Metal:} \quad M + MS = M \cdot MS \text{ (the eutectic)} \qquad (9$$

$$M \cdot MS + \tfrac{1}{2}O_2 = MO + MS \qquad (10$$

Note that this mechanism does not postulate oxidation of sulfide sulfur and assigns the role of solvent to the sulfide in the eutectic.

Formation of Sodium Oxide. For the sake of simplicity, the probable formation of sodium oxide during the experiments of Figures 14, 15 and 16 has not been mentioned. The formation of sulfide inclusions probably entails the formation of sodium oxide according to some reaction such as:

$$Na_2S + \tfrac{1}{2}O_2 + M = MS + Na_2O \qquad (11$$

In fact, hydrogen sulfide occasionally was detected when the strips were being heated in hydrogen, and an abrupt increase in weight occurred when sulfur dioxide was introduced at the end of Experiment 2. Both observations point to the occurrence of Reaction 11, the hydrogen sulfide probably being formed by the action of hydrogen on MS. Loss of sulfur in any form from the coated strip obviously reduces the chance of enhanced oxidation.

Conclusions

An effort has been made to explain the chemical effects of sodium sulfate in contact with high-temperature alloys by assuming that: 1) The salt itself is innocuous in the absence of reducing agents, 2) The presence of reducing agents triggers reactions that can become autocatalytic and destroy the alloy if sufficient sodium sulfate is present, and 3) Even with thin films of sodium sulfate, it is possible to get enhanced oxidation when the atmosphere is alternately reducing and oxidizing. Simple schematic mechanisms have been proposed for all these processes.

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Figure 18—Photomicrograph of Sample 3 of Table 1. (Unetched).

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DISCUSSIONS

Question by Edward D. Weisert, Kokomo, Ind.:
Was the extent of discoloration of the residual fuel ash a function of time as well as temperature?

Reply by Edward L. Simons:

The results described in this paper were obtained during 20-30 minute heating periods. Although the extent of discoloration of a given ash sample varied slightly with the time of heating, the relative order of darkening remained the same as that shown in Figures 2 and 4.

Questions by Andrew Dravnieks, Standard Oil Co. (Indiana), Whiting, Indiana:

1. It appears that triggering of sulfate attack by traces of chlorides, as described in one of the previous papers by the General Electric group, may be electrolytic. Also that potentials are supplied by local dissimilarities of contaminated surface, instead of an outside potential source, as in the present paper.
2. Would you expect that upon hardening of scale

the actual corrosion rate of the metal underneath would slow down?

3. If sulfide pits have been observed under scale, what is the reducing agent? Should not the reaction go in two steps: 1) Reduction of sulfate by metal, and 2) Sulfate attack on metals?

Replies by Edward L. Simons:

1. According to our suggested mechanism, the triggering phase involves the reduction of sodium sulfate. Our electrolytic experiments simply represent one way of initiating this reduction. Other reducing agents may produce the same triggering. We have no proof that such triggering necessarily involves electrolysis.

2. We have no information about the hardness of the scales as they exist on either laboratory or field specimens at the temperature of oxidation. The experiments with thin coatings of sodium sulfate demonstrated that in the absence of reducing conditions the oxidation rate was very slow whether the scale was hard (below the melting point of sodium sulfate) or molten (above the melting point).

3. The mechanism which we have suggested in Equations 1-4 does represent a two-stage process of reduction and oxidation. But we do not believe that the metal necessarily is the most important reducing agent. Although Type 310 steel itself may exert a reducing action, we have no proof that it can trigger the destruction of the alloy in the absence of other reducing conditions.

Any Discussions of This Article Not Published Above Will Appear in the June, 1956 Issue

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Part 2 of 2 Parts

Electrode Potentials *

By G. W. AKIMOV

(Continued from November, 1955 issue)

5. **Potentials of Active Cathodes and Anodes.** The potential of an electrode carrying a current usually differs from its potential when no current is flowing. This constitutes the so-called phenomenon of electrode polarization (cathodic polarization renders the electrode more negative while anodic polarization causes it to become more positive).

Figure 59 shows polarization curves for anodic and cathodic polarization presenting the changes in potentials of the two electrodes I and II as a function of current density I_D. The potential of the electrodes when no current is flowing is taken as the zero point on the axis of the abscissa. This is the original potential of the electrode which, depending on conditions, may be either reversible or irreversible. To the right of the zero point are plotted the values of the potential occurring during cathodic polarization, i.e., for the case when the electrode occupies the position of a cathode in a galvanic cell or when the electrode is connected with the negative pole of an outside source of current. To the left of the zero point are given values observed during anodic polarization. In this case the electrode acts as the anode of the cell, or it is connected with the positive pole of the current source. The type of the polarization curve depends on the nature of the metal itself, on the state of its surface and on the exterior conditions. Quite a pronounced effect is also exerted by the protecting films on the surface of the electrode.

A steeper raise of a cathodic curve or a steeper drop of an anodic curve corresponds to a stronger (easier) polarization of an electrode. Let us define as specific polarization, or polarizability, the change in electrode potential per unit of current density of the current applied to the electrode $\left(\frac{\Delta V}{I/cm^2}\right)$. It should be noted that polarizability has no relation whatever to the original electrode potential. To emphasize this point, the curves in Figure 59 are shown in such a way that the cathodic curve of Electrode I, which has a higher positive original potential than Electrode II, intersects the curve for Electrode II. In other words, specific polarization for Electrode I is greater than specific polarization of Electrode II. Polarization curves can have a very complicated shape which indicates that specific polarization changes with increasing current density. In the absence of films on the surface of electrodes in comparatively simple electrolytes and, in general, in the absence of any complicating conditions, both anodic and cathodic curves frequently can be presented by a logarithmic equation.

$$E = E_o \pm B \log I_D \qquad (19$$

in which E is the potential of electrodes carrying current of a given density, E_o the original potential of the electrodes, B a coefficient and I_D current density. This equation is not valid for a region close to the zero ordinate.

Forgetting for a moment many details and paying attention only to the intensity and direction of the changes in the electrode potentials at low current densities, it becomes possible to greatly simplify the polarization diagram and to use straight lines for both cathodic and anodic curves of the polarization diagram. Such a diagram is given in Figure 60. The equation of the polarization curve is

$$E = E_o \pm BI_D \qquad (20$$

The coefficient B is equal in this case to the specific polarization.

The question of polarization phenomena occurring on the electrode during the passage of the current may be explained in the following manner. Let us consider first cathodic polarization. In this case a discharge of positively charged ions takes place on the cathode. Then ions arrive on the cathode as excess electrons, for example, as $H^+ + e \rightarrow H$, or through formation of negatively charged ions from neutral molecules at the expense of excess electrons, for example,

$$0_2 \rightarrow 0 + 0$$
$$0 + H_2O + 2\,e \rightarrow 2HO^-$$

The passage of excess electrons from the material of the cathode to cations or molecules of the solution, which is a reduction or electron gaining process, can be considered as a characteristic feature of the cathodic polarization process. However, all processes of this kind consume time, so that a certain energy is required to make them occur rather rapidly. This energy may be similar to the activation energy of chemical reactions. In this manner, excess electrons reaching the cathode might not have enough time for reducing cations or molecules in the solution, as a result of which the electron density in the double layer increases and the negative potential of the electrode becomes larger. This is equivalent to the presence of a certain additional activation energy which leads to an easier passage of electrons on the particles of the solution thus causing an increasing velocity of their discharge process. The process of cathodic polarization is schematically presented in Figure 61.

* Chapter 3 of the book "Theory and Research Methods of Metallic Corrosion," published originally by the Publishing House of the Academy of Science, USSR, Moscow, 1945. This translation was prepared by R. B. Mears, Director of the Applied Research Laboratory, and J. D. Gat, Patent Department, both of the U. S. Steel Corporation.

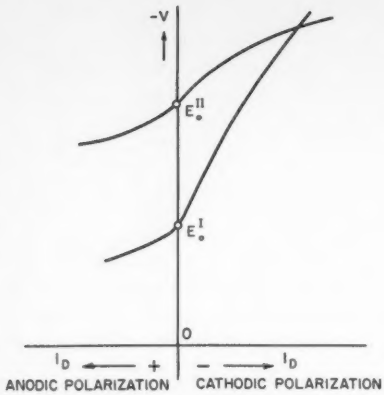


Figure 59—Schematic representation of polarization curves for electrodes I and II (Akimov).

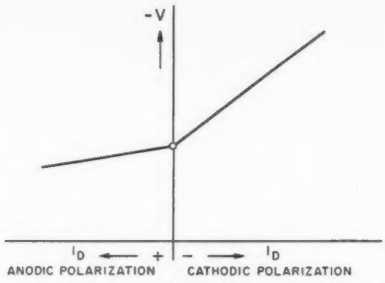


Figure 60—Simplified scheme for polarization curves (Akimov).

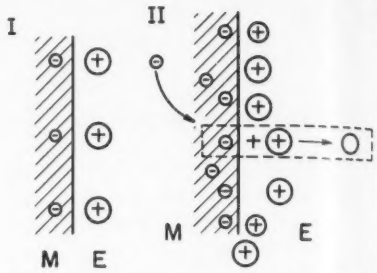


Figure 61—Schematic presentation of cathodic polarization (Akimov).

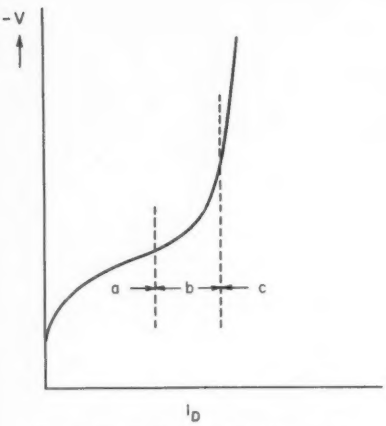


Figure 62—Cathodic polarization curve.

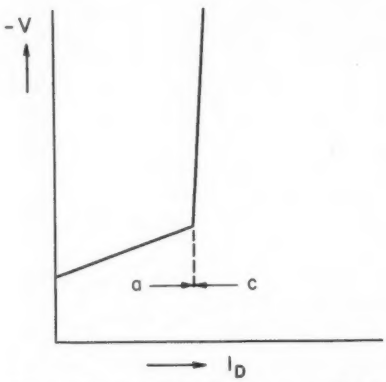


Figure 63—Simplified diagram of cathodic polarization.

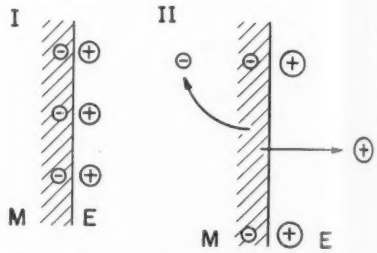


Figure 64—Schematic representation of anodic polarization (Akimov).

An insufficiently rapid supply of particles (ions or molecules) of the solution which receive these electrons may be considered as another cause of cathodic polarization. Let us assume that the concentration of these particles in a solution is not high and that the diffusion is powerless to restore rapidly the original value of concentration in the layer of the solution adjoining the cathode. In this case, a deficiency of particles in a layer next to the cathode occurs very soon, so that only a portion of the electrons flowing to the cathode can be transferred to these particles of the solution. As a result, the electron concentration in the double layer is increased again. Accordingly, this increases the concentration of positive particles in the positive film of the double layer. Thus, the negative charge on the electrode will reach a higher value, i.e., the potential of the electrode will become more negative. In other words, it can be said that the electrode is polarized to a certain value. This type of polarization is known as concentration polarization.

A polarization diagram for the case, in which the polarization is first associated with the retardation of the discharge process on the cathode (Section a), and then (at higher current densities when the process proceeds much faster) with the deficiency of particles needed for the electron transfer at the surface of the electrode (Section c), is shown in Figure 62. The intermediate Section b corresponds to the state where both above-mentioned factors extend their influence. A simplified diagram may be presented as two intersecting straight lines, Figure 63.

Anodic polarization is also connected with the retardation of the process taking place at the anode, i.e., with the passage of metallic ions into the solution. On account of this, the electron density at the surface of the electrode is reduced and the negative value of the potential is lowered, i.e., the potential becomes more positive. The process of anodic polarization is schematically represented in Figure 64.

Concentration polarization can also have a pronounced effect at the anode. When the diffusion process of the ions of the metal itself which have passed into the solution is much retarded as compared with the velocity of the process of ion transfer in the solution, a much higher concentration of the metallic ions can be expected at the surface of the metal as compared with the average concentration of the solution. Accordingly, a shift of the potential towards more positive values is to be expected.

Let us examine now, for example, the couple Cu-Zn in a 0.1 N solution of H_2SO_4, Figure 65. This couple

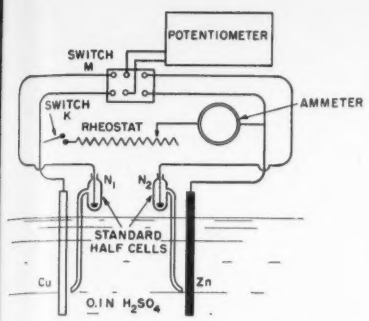


Figure 65—Scheme for determining current strength and potentials of an electro-chemical couple (Akimov).

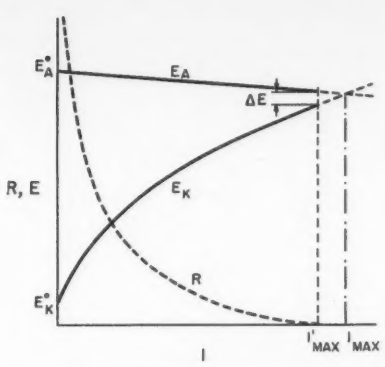


Figure 66—Changes of E_A, E_K, and R of an electrochemical couple as a function of current increase in the couple (Akimov).

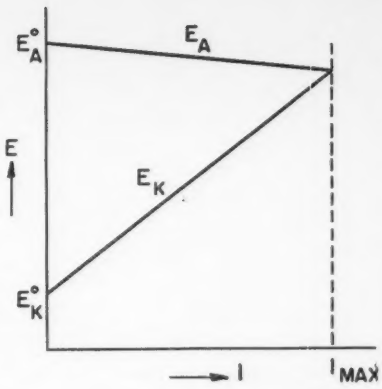


Figure 67—Schematic polarization diagram (Evans).

can be connected or disconnected by means of switch K, and its internal resistance can be raised by the rheostat R.

The values of electrode potentials of the electrodes of the couple discussed, Figure 65, can be measured with a potentiometer P and a switch M. At the beginning of an experiment the couple is disconnected (switch K is open) and one measures the original electrode potentials of copper and zinc in a solution of sulfuric acid in reference to a standard electrode. The current strength in a disconnected couple is, naturally, equal to zero. In this case, the electrode potentials are equal to $E_{Cu} = +0.25$ v and $E_{Zn} = -0.95$ v. It must be mentioned here that all potential values given in this book, with the exception of those specially mentioned, are given for the hydrogen scale, i.e., in reference to the standard hydrogen electrode, even when the measurements have been conducted using some other electrode. Therefore, the original difference of potentials, or EMF, of the couple is equal to 1.2 v. Now let us connect the couple while leaving a high outside resistance of the order of 10,000 ohms. With a sensitive galvanometer, the circuit will show a weak current of about 0.1 MA. A measurement of the electrode potentials of the working couple will show that both the anode and cathode potentials are slightly changed and the difference of the potentials is slightly decreased. When the resistance in the outside circuit is gradually decreased while the current strength and electrode potentials of the working electrodes are measured, the results obtained can be presented as a schematic diagram, in which current strength is plotted along the abscissa and corresponding electrode potentials of the anode and of the cathode are plotted along the ordinate, Figure 66. The dotted line on the same diagram shows the resistance of this system; also plotted as a function of current strength. One look at this diagram is sufficient to show that the potentials of the anode and cathode change when current flows in the circuit. When current increases, the anode becomes more positive (the curve E_A slopes downward) and the cathode reaches higher negative values (the curve E_K is directed upwards) i.e., the potentials of the cathode and of the anode approach each other. In other words, it may be said that the difference of potentials decreases in the present couple with increasing current.

The change of electrode potentials and the difference of potentials are, apparently, connected with the polarization of the electrodes occurring as soon as a current begins to flow through the couple. The polarization is directly proportional to the strength of the current, while cathode polarization is stronger here than the polarization of the anode. It may appear strange that the difference of potentials becomes less while current strength increases, but it should not be forgotten that the current strength in the couple increases as a result of voluntary decrease of resistance while the decrease of resistance is faster than the drop of potential difference. Only under this condition may the current strength in the couple become greater. Schematic diagrams of this type can be further simplified by the omission of plotting on it all details of the potential changes associated with the increased current strength and presenting the curves of potential variations as straight lines, Figure 67. The latter diagram is known as the Evans' polarization diagram named in honor of the scientist who proposed it first.[11,12]

It is not difficult to see that the Evans' diagram represents really a combination of two polarization curves characteristic of a corrosion couple, namely, the curve of anodic polarization of anodic areas and the curve of cathodic polarization of cathodic areas. This combination on a single diagram is possible only in the case when on the abscissa axis are plotted the values of current strength in the couple in place of current density, because at any ratio of anodic and cathodic areas the current strength of the anode is equal to that of the cathode and the scale used on the axis of abscissa becomes suitable for plotting both the anodic and the cathodic curves. Only in the instance when the area of anode is equal to the area of cathode, either current strength or current density may be plotted on the axis of abscissa. It is obvious that, when the areas of both electrodes and the curves of anodic and cathodic polarization are known, the Evans' diagram may be plotted from them. This dia-

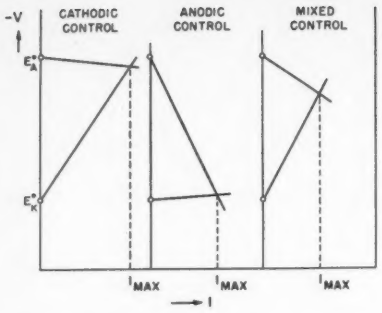


Figure 68—Schematic presentation of three basic types of polarization diagrams (according to Evans).

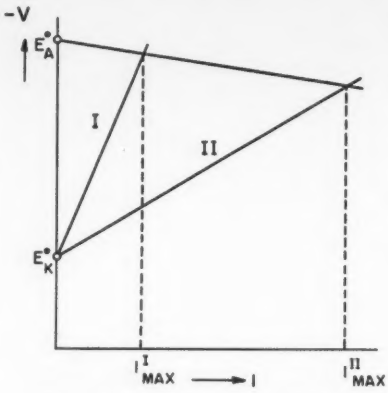


Figure 69—Diagram showing greater maximum currents being associated with lower polarization (Akimov).

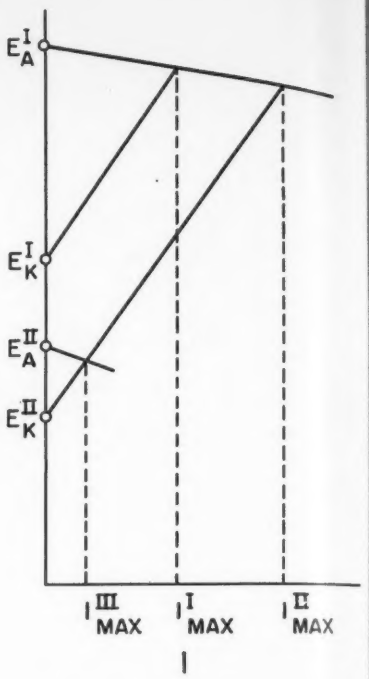


Figure 70—Schematic illustration of the influence of original potential difference on the maximum current value (Akimov).

gram is constructed, however, more frequently as the basis of direct experimental results.

When rheostat R is completely eliminated from the circuit and when the measuring device A, Figure 65, has a very low resistance, the external resistance may become very low. On the other hand, it is not possible to reduce the internal resistance of the couple to an infinitesimal value, because the normal functioning of the couple calls for a certain space between the electrodes which must be filled with the electrolyte. This space determines the internal resistance of the couple. In this light, it becomes impossible to reduce the total resistance of the couple to zero under any conditions. A certain slight difference of potentials ($\triangle E$) remains, therefore, at the end of this experiment, and this corresponds to the maximum current I'_{max} experimentally attainable, Figure 66.

Theoretically it is possible, however, to extend the curves of anodic and cathodic polarization to the intersection with I_{max}. It is obvious that at this point the potential of the cathode will become equal to that of the anode $E_K = E_A$, and the difference of potentials will become equal to zero. At the same time, this point corresponds to the theoretically possible maximum current of the couple. This can take place only when the resistance of the whole system is equal to zero. By artificial means, as by using polarization from an outside source, it is possible to attain this intersection point experimentally. Under actual practical conditions, we can only approach the intersection point of the polarization diagram without quite reaching it.

The Evans' diagram which has just been discussed, fully deserves to be called the basic diagram of corrosion. When the potentials of the diagram are related to the electrodes of a micro-element of a given corroding surface, the maximum current I_{max} represents the maximum current of the micro-element possible under given conditions. The latter, according to Faraday's law, is proportional to the material consumption of the anode, i.e., to the velocity of corrosion. In cases where it is possible to disregard the ohmic resistance of the system on account of its low magnitude, for example, when the solution has a high electrical conductivity, current strength will be defined by polarization alone and will have the maximum possible value. Current strength of a corrosion element having an appreciable ohmic resistance will always be less than its maximum value I_{max}. There is no escape from Ohm's law. A higher resistance always corresponds to a greater potential difference and to a weaker current. An approach to the intersection point of the polarization curves leads to a reduction of potential difference and simultaneously to a lesser ohmic resistance. Very close to the intersection point it maybe assumed, without a large error, that the whole surface has the same potential and the corrosion process takes place on an isopotential surface. It should not be forgotten, however, that this case is entirely different from the case when the same potentials are originally present at the whole interface metal-electrolyte. The same potentials over the whole surface are obtained in the above-mentioned case as a result of polarization alone. An approximate equality of all potentials is associated here with a very low ohmic resistance of the micro-elements. There is no need for specific mention that the same relations prevail in any macrosystem.

Let us point out certain major features of the Evans' diagram.

The maximum current may be determined basically by either the cathodic or the anodic curve. When the cathodic curve shows a greater slope than the anodic curve, the former determines the value of I_{max}, and vice versa. Let us examine an approximate diagram, in which polarization curves are presented

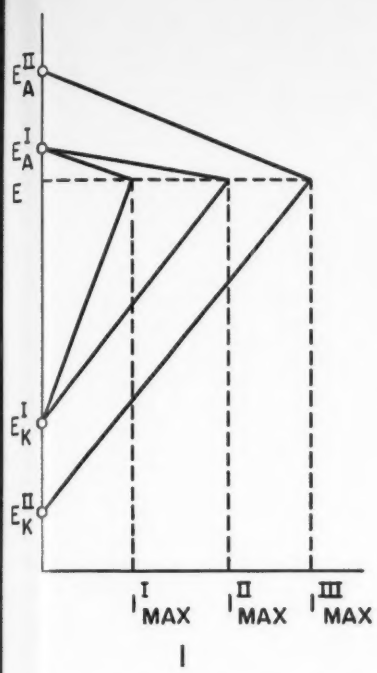


Figure 71—Diagram showing different values of $I_{max.}$ corresponding to identical values of E (Akimov).

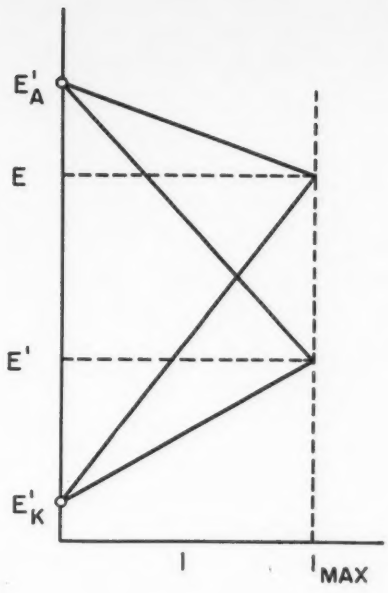


Figure 72—Diagram showing different values of E corresponding to the same value of $I_{max.}$

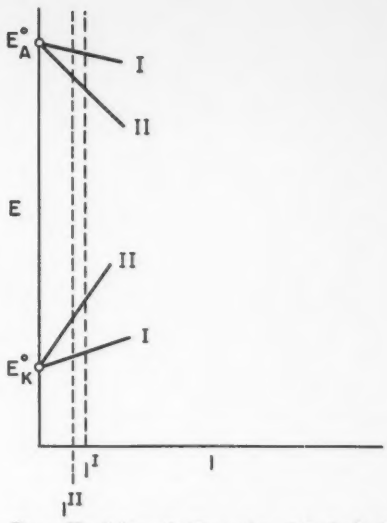


Figure 73—Schematic illustration of the lack of an appreciable effect of polarization on the magnitude of corrosion current I' when the ohmic resistance is high (I' is farm from $I_{max.}$) (Akimov).

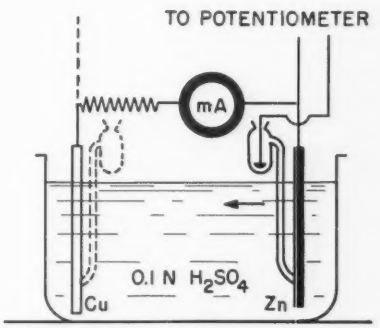


Figure 74—Scheme for measuring potential drop in an electrolyte (Akimov and Tomashev).

as straight lines, Figures 67. The equation for the cathodic line is

$$E_K = E^\circ_K - P_K I$$

where P_K is the cathodic polarization. In the same way, the equation for the anodic straight line can be written

$$E_A = E^\circ_A + P_A I$$

where P_A is the anodic polarization.

At the point of intersection corresponding to I_{max}, $E_K = E_A$ i.e.,

$$E^\circ_K - P_K I_{max} = E^\circ_A + P_A I_{max}$$

$$\text{or} \quad I_{max} = \frac{E^\circ_K - E^\circ_A}{P_K - P_A} \qquad (21$$

This equation shows that when $P_K \gg P_A$, the I_{max} will be basically determined by the value of P_K, i.e., by cathodic polarization and inversely when $P_A \gg P_K$, the I_{max} will be determined primarily by the anodic polarization. There is, of course, a possibility that P_K and P_A are of the same order of magnitude and both these values determine the strength of the maximum current. Accordingly, Figure 68 presents three basic types of polarization diagrams in which the strength of the current is determined by the cathodic effect, by the anodic effect, and by their combined effects. In Figure 69, it is shown that, with all other conditions being constant, lower specific polarization corresponds to higher values of the maximum corrosion current.

The influence of the original electrode potentials on the values of the maximum current strength can be seen from Figure 70. Greater difference of the original potentials leads to a greater current strength, other conditions being constant. When the original electrode potentials are close to each other, any appreciable currents can be expected only when the resistance of the corrosion elements is very low. With an identical value of original electrode potentials over the whole surface, no galvanic couples and, therefore, no current can be expected.

It should be pointed out, furthermore, that while the strength of the corrosion current is determined chiefly by polarization, i.e., when the ohmic resistance is low and the point corresponding to this current strength is close to the intersection point of the polarization curves on the polarization diagram, the same potential may correspond to different values of the maximum current, Figure 71. Conversely, the same value of the maximum current may correspond to different values of electrode potentials, Figure 72. When the value of the current strength of the corrosion element is far from the value of the maximum current, it can be concluded that ohmic resistance plays an important part, for example when the electrical conductivity of the solution is low. It might

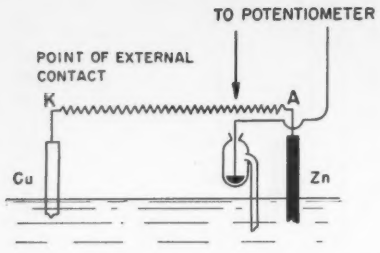


Figure 75—Scheme for measuring the potential during the motion of the contact in the exterior circuit (Akimov and Tomashev).

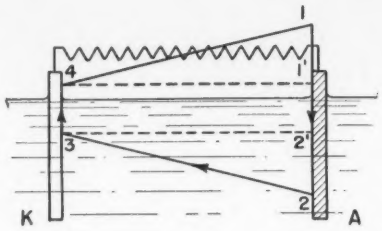


Figure 76—Potential drop in an electrochemical couple (Akimov and Tomashev).

appear in this case that this type of polarization curve has practically no effect on the current strength, Figure 73. In this instance it can be said that the corrosion process is limited by the ohmic resistance or that the process of corrosion is ohmically controllable.

6. **Change of Potentials in a Circuit Containing Active Electrodes.** Let us examine potential changes in the internal and in the external portions of the circuit[16] and turn back to the original couple Cu-Zn in a 0.1 N solution of H_2SO_4 closed through a moderately high external resistance of the order of the internal resistance of the couple, Figure 74. At the beginning of the experiment, the tip of the calomel electrode is located at the very surface of the anode; later we shall move it toward the cathode measuring the potentials at given intervals, for example at each centimeter. Meanwhile, the external contact may be left stationary directly at the anode (zinc), as it is shown in Figure 74.

These measurements show that the potential becomes more positive proportionally to the distance from the zinc. It is evident that a maximum potential value will be found at the moment when the point of the standard electrode almost reaches the copper electrode. On passing the point of the external contact from zinc to copper (dotted line of Figure 74) one obtains even more positive values.

These results show that, in measuring potentials of the electrodes of an operating couple, it is quite important to have the tip of a standard electrode as close as possible to the surface being measured, and the point of the external contact as close as possible to the electrode to be measured.

Before answering the question of what the explanation is for the potential changes during the motion of the standard cell tip, another experiment with the same Cu-Zn couple in sulfuric acid is in order. Let us move the point of the external contact from point A (the anode) to point K (the cathode), holding the position of the tip of the standard cell at one of the electrodes, for example zinc, constant, Figure 75. It will be noted that in this case also the potential changes in such a way that on motion of the contact from zinc to copper the potential becomes more positive, and *vice versa*.

Another important experimental result should be noted. When the external resistance is greatly increased, i.e., the resistance of the conductor between the anode and cathode, until it becomes many times higher than the internal resistance, the values of the potentials will be pronouncedly affected by the motion of the external contact point and affected little by the position of the internal contact (the tip of the standard cell). On a very large increase of the external resistance, the potential remains practically constant when the internal contact changes its position. Conversely, a greatly reduced external resistance leads to a slight effect caused by the location of the external contact point, and a pronounced influence exerted by the position of the internal contact. With a very low external resistance (a short circuit), the motion of the external contact point has practically no effect on the values of potentials being measured.

An explanation of potential changes occurring with the change of position of either internal or external contacts requires a study of potential changes over the whole circuit. When a couple is active, i.e. electrons are moving in the conductors and ions in the electrolyte, it may be assumed that an electric field exists in the conductors and in the electrolyte between the electrodes. In this case, the changes of potential which interest us are really changes of the potential of an electric field.

At the anode one can see, Figure 76, a potential change 1 to 2 while in the electrolyte a gradual change takes place towards the cathode (in the present case along the straight line 2-3, but a straight-line function is not always obligatory). At the cathode, we again have a potential change 3-4 which has an opposite sign to that of the anode and, finally, again a gradual change of the potential (an increase of it) along the straight line 4-1 taking place in the external portion of the circuit. The diagram of Figure 76 shows that horizontal lines drawn from points 3 and 4 perpendicular to the 1-2 section will divide the latter into two sections, the upper one 1-1′ corresponding in magnitude to the potential drop in the external conductor and the lower one 2′-2 corresponding to the potential drop in the electrolyte.

The active potential difference in our couple is equal to the sum of the potential drops in the external and in the internal portions of the circuit, i.e.

$$V_a = E_A - E_K = (1-2)-(3-4) = (1-1') + (2-2')$$

It should be noted that we have written $E_A - E_K$ and not conversely, since, for simplicity sake, we did not take into consideration the negative signs of the sections.

In the following and similar diagrams we shall always indicate the change of potential in a metallic conductor by the upper line, while we shall use the lower line for presenting potential changes in the electrolyte between the electrodes.

Let us assume now that the external resistance is much greater than the internal one and the drop of potential will therefore take place practically completely in the external conductor. The corresponding

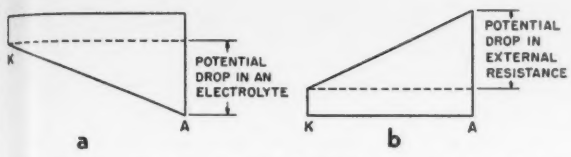


Figure 77—Potential drop in an electrochemical couple with (a) low external resistance and (b) low internal resistance.

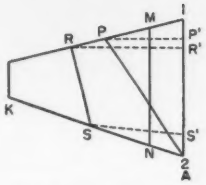


Figure 78—(Left) Diagram illustrating intermediate potentials (Akimov and Tomashev).

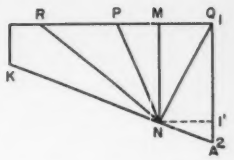


Figure 79—(Right) Diagram illustrating intermediate potentials in a couple having a low external resistance (Akimov and Tomashev).

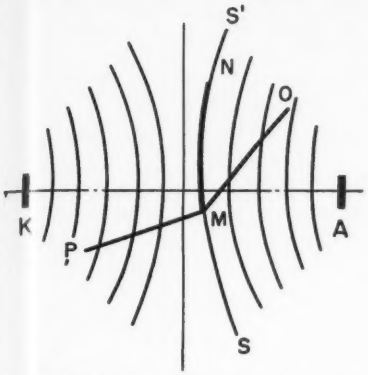


Figure 80—Potential change on moving across and along equipotential surfaces (Akimov and Tomashev).

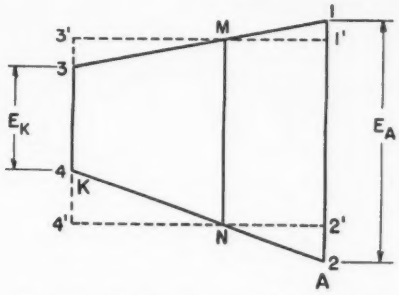


Figure 81—Diagram illustrating the calculation of an intermediate potential (Akimov and Tomashev).

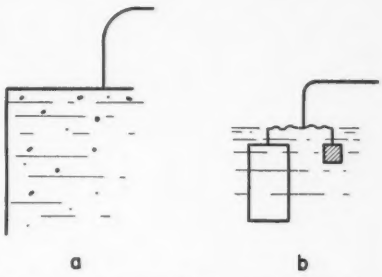


Figure 82—Diagram illustrating a complex electrode as a binary electrode (Akimov).

diagram will have the shape given in Figure 77b. When, on the other hand, the external resistance is very low, (the couple is short circuited), the potential drop will occur practically completely in the electrolyte, Figure 77a.

Suppose we have a couple, Figure 78, in which the potential distribution is analogous to that described above. When the external contact is located directly at the anode and the internal contact (the tip of a standard cell) closely approaches the anode, the measurements show the whole potential change on the anode. The same can be said about the cathode when both the internal and the external contacts are as close as possible to the cathode. On placing the internal and external contacts respectively at M and N, the potential corresponding to the section MN will be measured. When the internal contact is left at the anode, for example, at the point 2, while the outside contact is placed at P on the external conductor, the potential measured will be equal to the projection of the section 2-P on the vertical, i.e. 2-P′.

At any position of the points of the internal and external contacts one measures, in general, a potential equal to the projection of the straight-line section defined by the points of contact on a vertical, so that for the section R-S, for example, the corresponding projection is R′S′.

When a couple is short circuited, any displacement of the external contact does not have any effect on the magnitude of the potential being measured, as it can be seen in Figure 79 in which, in this case, all sections N-M, N-Q, N-P, etc. have the same projection 1-1′.

In this light, the results of experiments connected with the location of contacts in the binary-electrode system become clear. It remains to analyze the effect of the displacement of the internal contact not from one electrode to the opposite one, but to the side, i.e. at an angle to the straight line connecting the electrodes. Let us assume that we have two moderate-size electrodes placed at a certain distance from each other. Then the projection of these two electrodes in a horizontal plane and the corresponding electrical field in the electrolyte may be presented as shown in Figure 80. The field is represented here as equipotential lines. In the general case, the potential changes here from the anode to the cathode following a smooth curve. This potential will remain the same when it is determined along any of the equipotential curves. Thus, the displacement of the internal contact along MN would not change the potential, which corresponds to the equipotential surface S-S′, while the displacement of the contact in the direction of M-O or M-P, associated with cutting of the equipotential lines, changes the values of the potential under measurement.

In conclusion it should be noted that each intermediate potential might be considered either as a cathode potential reduced by the sum of the potential drop to the external contact and the potential drop to the internal contact (proper attention being paid to signs involved) or as the anode potential increased by the corresponding value. This is clearly shown in Figure 81, in which

$$MN = E_A - (1-1') - (2-2') = E_K + (3-3') + (4-4').$$

where $1-1'$ and $3-3'$ are corresponding potential changes in the external portion of the circuit and $2-2'$ and $4-4'$ are corresponding changes in the electrolyte. In the following, the portion of the circuit

from the anode to the points of the external and the internal contacts will be considered as the anodic portion of the circuit (for example 1-2-N-M in Figure 81) and the portion of the circuit from the cathode to the contact points as the cathodic portion of the circuit (for example 3-4-N-M).

When the current strength i of the couple is known, the value of any intermediate potential for a couple having electrodes free from polarization and having potentials E_A and E_K can be expressed analytically. This relates to a case when ohmic resistances are sufficiently high and the polarization of electrodes can be disregarded.

The potential drop in any section of a circuit is equal to the product of the current strength and the resistance of the corresponding section:

$$\begin{aligned} E_{MN} &= E_A + i\,(R_A^{\text{internal}} + R_A^{\text{external}}) \\ &= E_K - i\,(R_K^{\text{internal}} + R_K^{\text{external}}) \\ E_{MN} &= E_A + i\,R_A = E_K - i\,R_K \end{aligned} \qquad (22$$

where R_A^{external} is the external resistance of the anodic portion of the circuit, R_A^{internal} the internal resistance of the anodic portion of the circuit, R_A the sum of the resistances in the anodic portion of the circuit. For the cathodic portion, we have analogous symbols (R_K^{external}, R_K^{internal} and R_K).

Current strength i must be equal to the acting potential difference divided by the total resistance of the circuit ($\Sigma R = R_A + R_K$).

$$i = \frac{E_K - E_A}{\Sigma R} = \frac{E_K - E_A}{R_A + R_K} \qquad (23$$

substituting this expression in equation (22) we have

$$E_{MN} = E_A + \frac{E_K - E_A}{R_A + R_K} \cdot R_A = E_K - \frac{E_K - E_A}{R_A + R_K} \cdot R_K \qquad (24$$

or

$$E_{MN} = E_A + (E_K - E_A) \cdot \frac{R_A}{R_A + R_K} \qquad (25$$

$$E_{MN} = E_K - (E_K - E_A) \cdot \frac{R_K}{R_A + R_K} \qquad (26$$

The latter expressions (25 and 26) can be easily further transformed, thus

$$E_{MN} = E_A + (E_K - E_A) \cdot \frac{1}{1 + \frac{R_K}{R_A}} = E_K - (E_K - E_A) \cdot \frac{1}{1 + \frac{R_A}{R_K}} \qquad (27$$

These equations show clearly that the value of an intermediate potential MN does not depend on the absolute value of R_A and R_K but on their ratio. A larger R_K, i.e. the resistance of the cathodic portion of the circuit, as compared with R_A, i.e. the resistance of the anodic portion of the circuit, leads to a closer approach of the intermediate potential E_{MN} to the potential of the anode; inversely a reduction of R_K brings the intermediate potential closer to the potential of cathode.

7. Potentials of Complex Electrodes. Practical experience frequently brings us in contact with complex electrodes. Of first importance among them are alloys having a complex structure, such as $\alpha + \beta$ brass, silumin (aluminum-silicon alloy), steel (Fe-Fe_3C), cast iron (Fe-Fe_3C-C), etc. and the question arises regarding the nature of the electrode potential associated with such a complex electrode.

In order to solve the problem, let us make use of the models previously employed.

Let us assume that the material of a complex electrode consists of two structural compounds, a matrix and inclusions. Then, using certain simplifications, such as that an electrode may be considered as a binary electrode, Figure 82, two parallel cases have to be considered here, one when the ohmic resistances in the system are not large but where account must be taken of polarization alone and the other when ohmic resistance is high enough to permit us to disregard polarization completely. Let us first examine the former case using the simplified polarization diagram of Figure 67.

The equation of the cathodic polarization curve is:

$$E_K = E^\circ_K - P_K I$$

and the equation of the anodic polarization curve is:

$$E_A = E^\circ_A + P_A I$$

let us assume

$$E^\circ_K - E^\circ_A = V^\circ \text{ and } P_K + P_A = P.$$

Then the value of the total potential E_{tot} corresponds to the maximum corrosion current I_{max} may be determined from the postulate $E_K = E_A$

$$E_{tot.} = E^\circ_K - P_K I_{max} = E^\circ_A + P_A I_{max.} \qquad (28$$

hence

$$I_{max} = \frac{E^\circ_K - E^\circ_A}{P_K + P_A} = \frac{V^\circ}{P}$$

and

$$E_{tot.} = E^\circ_K - P_K \frac{V^\circ}{P} = E^\circ_A + P_A \frac{V^\circ}{P} \qquad (29$$

From these simple relations it follows that the total potential E_{tot} of a complex polarized electrode becomes more negative with the increasing negative value of E°_A and with decreasing polarizability P_A. A larger positive value of E_K and a smaller value of P_K lead to a more positive total potential of a complex electrode.

Since values of P_K and P_A are directly connected with the areas of electrodes F_K and F_A, one has $P_K = B_1 F_K$ and $P_A = B_2 F_A$, where B_1 and B_2 are the specific polarizability of the cathode and the anode. This leads to the conclusion that, in general, the total potential becomes more negative with an increased area of the anodic constituent of complex electrodes.

Passing to the real shape of polarization curves,

TABLE 9—Measurements of the Total Potential of the Cu-Zn System in Different Solutions. Potential Values Were Determined Against 1 N Calomel Electrode.

Solution	Total Potential (Experimental)	Pot. of Active Cathode	Pot. of Active Anode	Total Potential (Calculated)	Electrode Potential of Cu	Electrode Potential of Zn
3% NaCl+0.5% H_2O_2	—0.883	—0.831	—0.940	—0.885	—0.090	—0.998
1 N HCl	—0.955	—0.864	—1.048	—0.956	—0.248	—1.049

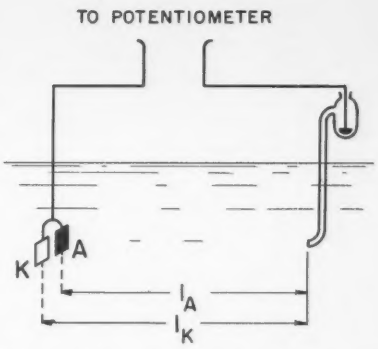


Figure 83—Measuring the electrode potential of a complex electrode (Akimov).

which is much more complicated than their linear representation, does not change the substance of the above deductions, merely rendering the relation among the values somewhat more complicated.

Let us now examine the other limiting case when ohmic resistance is so high that the polarization may be disregarded. Such a case is conceivable for a very weakly conducting electrolyte, for example tap water. For this case, we shall first consider a model consisting of two small electrodes having the same area $F_K = F_A$ connected through a certain moderate resistance in such a manner that the external resistance R^{ex} is much smaller than internal resistance R^{in}, Figure 83.

The tip of the standard cell is placed at a sufficient distance from both electrodes so we may consider distance l_k and l_a from each as equal. Then the position of the tip of standard has no effect on the measurements when R^{ex} is low.

Internal resistance is defined, as it is evident, by the area of the electrode and by its distance from the standard cell. Since $l_A = l_K$ and $F_A = F_K$, the internal resistance of both anodic and cathodic circuits is the same, i.e. $R_A = R_K$.

According to equation (25 the value of the total measured potential E_{tot} can be expressed as:

$$E_{tot} = E_A + (E_K - E_A) \cdot \frac{R_A}{2R_A} = E_A + \frac{E_K - E_A}{2} = \frac{E_A + E_K}{2} \qquad (30$$

In this manner, we measure a potential equal to one half of the sum of the potentials of the anode and cathode of an active couple.

The case which has been examined is, however, the simplest one. Practical work very frequently brings attention to electrodes in which anodic and cathodic areas are not equal. Before examining this more complicated case it may be pointed that the internal resistance may be considered as approximately proportional to the square root of the electrode area, i.e.

$$R \cong \frac{K_l}{\sqrt{F}}$$

where K_l is the coefficient of proportionality.

In this light it becomes possible to rearrange equation (25, while taking cognizance of the equation

$\frac{R_K}{R_A} \cong \sqrt{\frac{F_A}{F_K}}$ in the following manner:

$$E_{tot} = E_A + (E_K - E_A) \cdot \frac{1}{1 + \sqrt{\frac{F_A}{F_K}}} \qquad (31$$

Let us assume now that F_A is greatly reduced, as compared to F_K, while maintaining $l_A = l_K$ as before. Then the total potential measurable with equation (31 will approach E_K; conversely, a decrease of the cathode area will bring the total potential closer to E_A. On bringing the tip of the standard cell rather close to the electrodes, i.e. by rendering distance 1 commensurate to the distance between the electrodes, it will be noted that the position of the standard cell tip in respect to the electrodes effects the value of potentials being measured.

Direct experiments support expressions derived by us for the total potential E_{tot}. This potential of the Cu-Zn couple has been measured in different solutions in such a fashion that the tip of the standard (calomel) electrode was equidistant from the anode and the cathode. The areas of copper and zinc electrodes also were equal. The results of these determinations are given in Table 9, in which the values of potentials are presented in volts using a 1N calomel electrode as a standard.

Since the area of electrodes is the same and the distance $l_A = l_K$, the total potential must be equal to the arithmetical average of the potentials of active anode and cathode. The calculated values check reasonably well with those measured experimentally. The last two columns present electrode potentials of copper and zinc in the same solutions, indicating that it would be erroneous in this case to use the electrode potentials of the metals in place of the potentials of active anode and cathode.

Let us now measure an electrode potential of an alloy having a complex structure. The dimensions of the inclusions are small and, unless a very small scale is used, their distribution in the matrix may be considered uniform, Figure 84. Since these inclusions are small, being much smaller than the area of the opening of the standard cell tip and are distributed uniformly, placing the tip of the standard cell close to the surface of the electrode being investigated does not affect the results of the determinations.

When the dimensions of the inclusions are very large and the opening of the tip of the standard cell is small, of the order of the dimensions of the inclusions, the position of the standard cell tip in respect to the electrode has an appreciable effect on the results of the measurements.

Let us now examine the most complicated case when both polarization and ohmic resistance have an effect using the approximate linear diagram of Figure

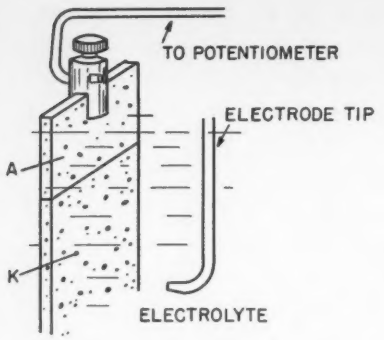


Figure 84—Determination of total potential of a complex electrode (Akimov).

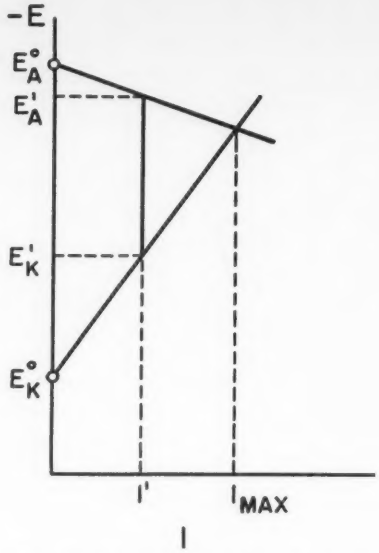


Figure 85—Schematic polarization diagram for a complex electrode (Akimov).

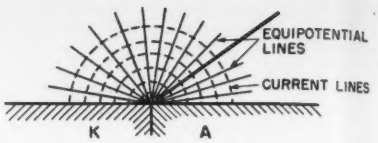


Figure 86—Current and equipotential lines for a couple composed of two electrode strips in one plane (Akimov).

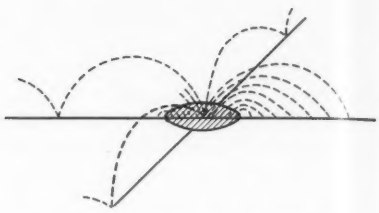


Figure 87—Current lines in the vicinity of inclusions in a plane (Akimov).

85. Let us assume that ohmic resistance is equal to W. The equation of the polarization curve is:

$$E_K = E°_K - P_K I$$

and

$$E_A = E°_A + P_A I$$

as before

$$E°_K - E°_A = V°$$

and

$$P_K + P_A = P$$

The value of the maximum current is, as it has been shown before, equation (21:

$$I_{max} = \frac{E°_K - E°_A}{P_K - P_A} = \frac{V°}{P}$$

The magnitude of current I′ corresponding to the resistance of w of the system is equal to

$$I' = \frac{E'_K - E'_A}{W}$$

The values of potentials E'_K and E'_A are respectively

$$E'_K = E°_K - P_K I' \quad (32$$

$$E'_A = E°_A + P_A I' \quad (33$$

From the diagram of Figure 85 it follows:

$$E'_K - E'_A = V° - P_K I' - P_A I'$$

hence,

$$I' = \frac{V°}{P_K + P_A + W} = \frac{V°}{P + W} \quad (34$$

The values of electrode potentials corresponding to the resistance W of the system are equal to

$$E'_K = E°_K - P_K \frac{V°}{P + W} \quad (35$$

$$E'_A = E°_K + P_A \frac{V°}{P + W} \quad (36$$

The values of the total potential E_{tot} to be measured depend on the position of the contacts in the external and in the internal portions of the system, in other words on the ratio $W_A : W_K$

On recalling that $W_A + W_K = W$ we have

$$E_{tot} = E_A - (E_A - E_K)\frac{W_A}{W}$$

and

$$E_{tot} = E°_A + P_A \frac{V°}{P + W} - \left(E°_A + P_A \frac{V°}{P + W} - E°_K - P_K \frac{V°}{P + W}\right)\frac{W_A}{W} \quad (37$$

after conventional algebraic rearrangement we have

$$E_{tot} = E°_A + V° \frac{P_A + W_A}{P + W} \quad (38$$

or

$$E_{tot} = E°_K - V° \frac{P_A + W_K}{P + W} \quad (39$$

Complications introduced by the actual shape of polarization curves in the above equations express themselves only by a more complex type of the relation between the values involved.

An electrode potential of a binary system will depend, therefore, in this case on the values of the original potentials $E°_K$ and $E°_A$, on polarization characteristics P_K and P_A (and, therefore, on the electrode areas F_K and F_A), on resistance W of the system and on the measuring method used, i.e., the point of introducing the outside contact and the tip of the standard cell, in other words on the ratio $W_K : W_A$.

Concurrently attention may be called on the following phenomenon. When a polarized system is being examined in which the ohmic resistance practically does not enter consideration, the value of the potential all over the surface of the corroding metal is about the same. In other words, the corrosion proc-

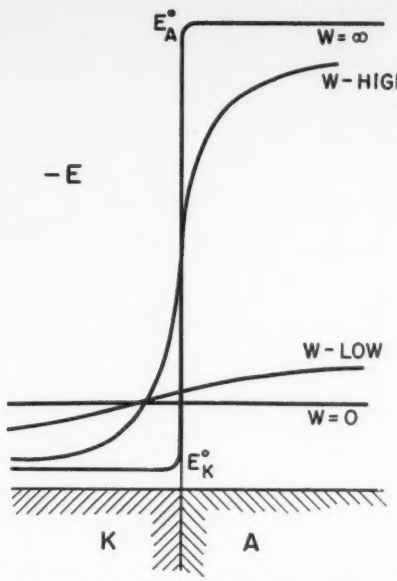


Figure 88—Changes of electrode potential near the boundary between anode and cathode (Akimov).

ess takes place on an isopotential surface. We have already mentioned that isopotentiality of this type always follows the original heterogeneity of the surface. With the same original electrode potentials all over the surface, it is not possible to speak about an electrochemical process of metal corrosion. When appreciable ohmic resistances are present, no isopotential corrosion can take place, even in the presence of comparatively high polarization, because different points of the surface have, in this case, varying electrode potentails.

It is possible, however, to measure a certain total potential E'_{tot} which has intermediate values between E'_K and E'_A. The magnitude of E'_{tot} depends in this case on the method of measurement, i.e. on the practice used for inserting the measuring circuit in the system. Strictly speaking, E'_{tot} expresses here a potential of a certain point on the electromagnetic field between the electrodes of an active galvanic cell.

Until now we have been using models representing binary structures as separate electrodes connected in the conductor. A closer approach to the time conditions will be achieved when the external conductor is replaced by direct contact of the electrodes. Such a system is distinguished from a system of microelements by dimensions alone.

Let us examine the changes of the electrode potential on such a model.

The direction of the lines of force and of the planes indicating equipotentiality which are perpendicular to the former can be schematically presented in the simplest case of two strip electrodes as semi-cylinders and planes which can be projected in a vertical plane as a semi-circle and straight lines, Figure 86.

A somewhat more complicated case is observed when the width of these strips is different. Figure 87 shows schematically the still more complicated instance of a round inclusion.

One characteristic feature common to all these examples is that portions of the electrodes bordering each other are connected by the shortest lines of force. Any point located at a greater distance from this boundary, has a proportionally longer line of force.

Two limiting cases should be considered here. Let us assume that the electrolyte has a very high resistance so that even for very short distances the resistance is equal to infinity. Then the potential distribu-

TABLE 10—Electrode Potentials of Metals in Typical Electrolytes, Millivolts (Clark and Akimov)

	3% NaCl				0.1*N*HCl				0.1*N*HNO_3				0.1*N*NaOH			
METAL	1 Min.	5 Min.	Stirring	Cleaning	1 Min.	5 Min.	Stirring	Cleaning	1 Min.	5 Min.	Stirring	Cleaning	1 Min.	5 Min.	Stirring	Cleaning
Be	— 760	— 764	— 753	—1016	— 724	— 710	— 712	— 717	— 397	— 322	— 273	— 341	— 526 — 746	— 526 — 666	— 516 — 664	.... —1216
Mg	—1418	—1401	—1432	—1500	—1622	—1575	—1595	—1596	—1270	—1246	—1237	—1220	— 79– —1086	— 866 —1137	— 700 —1123	.... —1484
Al	— 577	— 571	— 551	—1221	— 493	— 497	— 478	— 916	— 320	— 383	— 380	— 804	—1403	—1382	—1371	—1386
Si	— 301	— 378	— 358	— 579	— 378	— 391	— 371	— 466	...	— 76 — 239	....	— 422	— 460	— 404	— 393	— 896
Nb	— 202	— 176	— 166	— 615	+ 153	+ 117	+ 115	— 348	— 25	+ 1	+ 16	— 329	— 477	— 461	— 452	— 832
Cr	— 32	— 109	— 82	— 659	— 39	+ 56	+ 74	— 482	— 9	+ 115	+ 141	— 209	— 72 — 412	— 60 — 206	— 54 — 182	.... — 862
Mo	+ 125	+ 105	+ 83	— 362	+ 351	+ 330	+ 324	— 92	+ 350	+ 329	+ 325	— 19	— 330	— 288	— 270	— 660
Mn	— 995	—1000	— 948	—1146	— 968	— 888	— 865	— 857	— 752	— 730	— 750	— 777	—1000	— 475 — 720	— 216 — 386	—1213
Fe	— 255	— 300	— 255	— 361	— 328	— 319	— 276	— 283	— 240	— 268	— 116	— 94	— 161	— 100	— 94	— 570
Co	— 146	— 144	— 166	— 382	— 147	— 166	— 110	— 108	— 19	— 65	— 46	— 15	— 147	— 93	— 82	— 532
Ni	— 23	— 7	+ 66	— 264	— 31	— 58	+ 44	+ 22	+ 98	+ 128	+ 186	+ 189	— 128	— 38	— 27	— 453
Cu	+ 70	+ 58	+ 34	— 125	+ 154	+ 146	+ 76	— 135	+ 253	+ 215	+ 193	+ 257	+ 27	+ 33	+ 12	— 200
Ag	+ 227	+ 228	+ 216	— 72	+ 277	+ 285	+ 281	— 4	+ 250 + 490	+ 276 + 491	+ 277 + 468	+ 169 + 254	+ 300	+ 259	+ 253	+ 35
Au	+ 250	+ 253	+ 258	+ 46	+ 348	+ 350	+ 350	+ 117	+ 442	+ 456	+ 454	+ 345	+ 245	+ 217	+ 200	+ 83
Zn	— 772	— 782	— 750	— 818	— 769	— 756	— 747	— 752	— 688	— 681	— 650	— 643	—1126	—1131	—1120	—1123
Cd	— 530	— 531	— 520	— 526	— 510	— 515	— 510	— 510	— 385	— 387	— 388	— 389	— 565	— 500	— 487	— 667
Hg	+ 302	+ 303	+ 286	+ 297	+ 330	+ 330	+ 332	+ 331	+ 643	+ 626	+ 587	+ 479	+ 175	+ 174	+ 163	+ 158
Te	— 443	— 450	— 450	— 506	— 410	— 457	— 474	— 487	— 398	— 410	— 440	— 451	— 425	— 445	— 474	— 482
Sn	— 216 — 429	— 205	— 192	— 390	— 248	— 256	— 251	— 251	— 122	— 121	— 126	— 127	— 856	— 861	— 847	— 841
Pb	— 288	— 312	— 298	— 334	— 233	— 235	— 236	— 237	— 216	— 219	— 223	— 224	— 511	— 512	— 506	— 505
Sb	— 59	— 56	— 62	— 181	+ 195	+ 197	+ 193	+ 161	+ 196	+ 197	+ 192	+ 137	— 463	— 467	— 448	— 490
Bi	— 40	— 24	+ 8	— 109	+ 168	+ 165	+ 178	+ 176	+ 233	+ 234	+ 246	+ 233	— 251	— 245	— 244	— 290

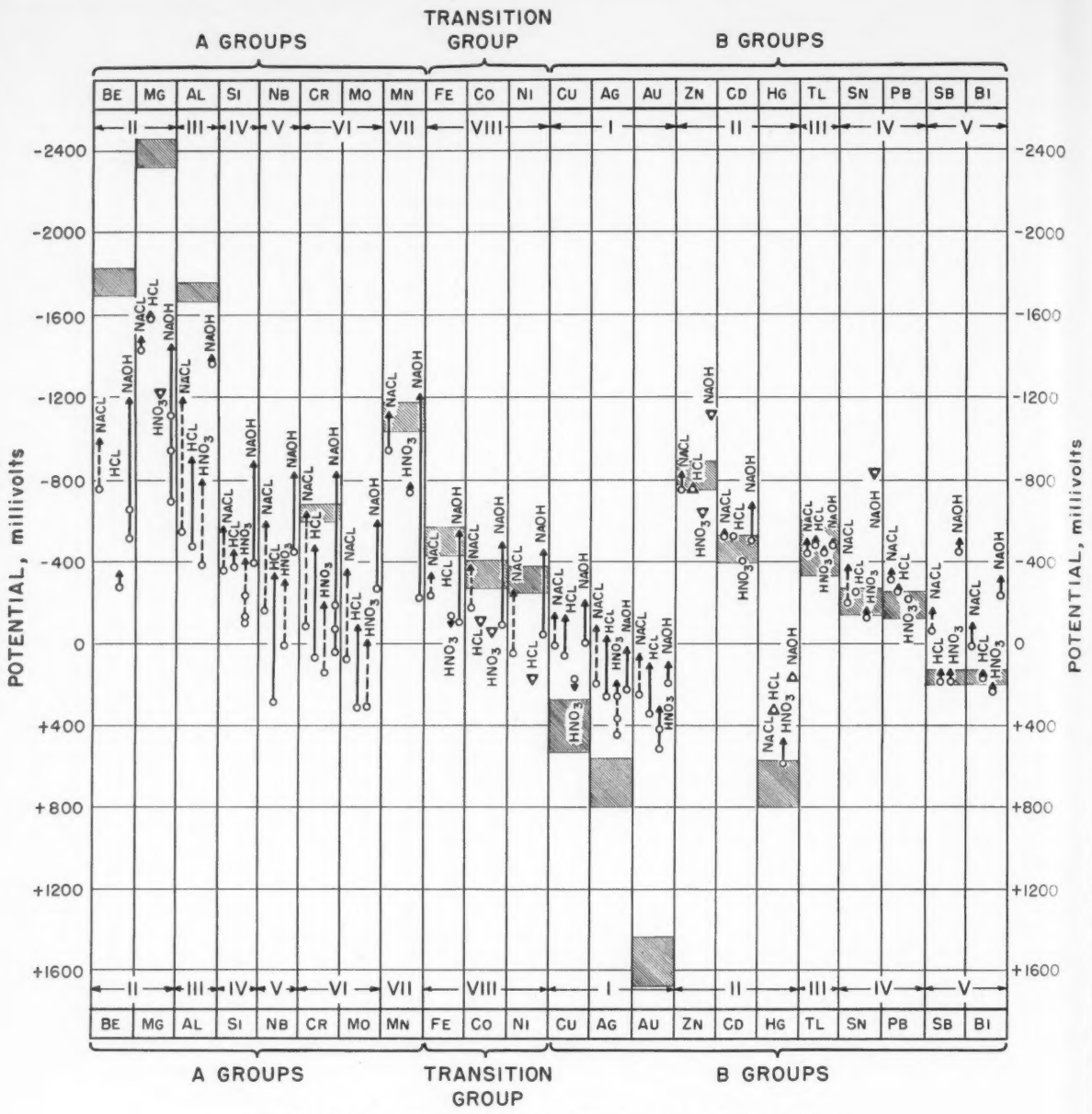


Figure 90—Electrode potentials of metals in different solutions (Clark and Akimov).

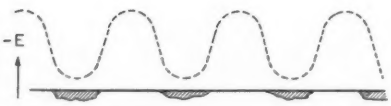


Figure 89—Changes of the electrode potential on a surface containing inclusions (Akimov).

tion on the electrodes of a model might be given as the w = ∞ curve in Figure 88. Potential values are plotted here as a fraction of the distance of a point on the surface from the boundary between the anode and cathode. A potential change is observed on passing from anode to cathode. Both cathode and anode retain the original values of E°_{K} and E°_{A}, because the high resistance of the liquid actually keeps the electrodes disconnected. An opposite case, in which the electrolyte has high conductivity so that for any distance the resistance may be held equal to zero is shown in Figure 88 as a straight line parallel to the abscissa, the ohmic resistance having no appreciable effect. The curve w-high, Figure 88, relates to an intermediate case when the resistance has an appreciable effect. Close to the cathode-anode boundary, the electrode potential changes comparatively sharply, because the ohmic resistance plays a part proportionally increasing with the distance from the boundary. The curve of Figure 88 w-low corresponds to the case of a greater electrolyte conductivity as compared with the previous case.

Figure 89 presents variations of the electrode potential on a surface containing a series of inclusions, where an appreciable effect is produced both by ohmic resistance and by polarization.

8. **Potentials of Complex Electrodes of the Film-Pore Type.** The influence of protective films on electrode potentials of different metals[17] is best seen from Table 10 and Figure 90. The measurements were made by first determining the electrode potential of a metal in a conventional manner and then during a continuous cleaning of the surface by means of a carborundum rod. This cleaning removed the original protective film and the film of corrosion products formed during the operation of corresponding galvanic cells. It is possible therefore to assume that the measurements give the results for clean metallic surface free from any film. In this manner, comparing an electrode potential measured in the usual way (film-coated surface) and measured while the metal is being cleaned (film-free surface) give some idea as to the effect of protecting film on the electrode potential of the metal. In Figure 90 the above comparison is made in the following fashion: For each metal and for each medium the butt end of an arrow marks the value of an electrode potential measured in the usual way without cleaning and the point of the arrow shows the magnitude of the potential during cleaning.

In the diagram of Figure 90, the negative values of the potentials are plotted upwards, so that an upward direction of arrows indicates potentials becoming less noble on film removal, while the length of these arrows corresponds to the magnitude of this change. Areas corresponding to the values of reversible potentials of metals in solutions having a concentration of their ions varying in the range 0.001-1.0 N are shaded in this diagram for the purpose of orientation.

The diagram of Figure 90 indicates that the ability to form strong protective films decreases, in general, from left to right of the diagram.

Protective films are most easily formed on metals of the A group of the periodic system of elements, namely Be, Mg, Al, Nb, Cr, Mo, Mn. In this case cleaning changes the electrode potentials by 300-1000 millivolts. The transitional group, namely Ni, Fe, Co, shows a potential drop on cleaning ranging between 200 and 500 millivolts, i.e. the ability for forming protective films is less marked for this group.

The first group B, namely Cu, Ag, Au, still forms some film, but the variation of the potentials is much smaller here being of the order of 100-200 millivolts. The remaining metals of the B group produce protective films only occasionally and the changes of potentials in the negative direction on cleaning but seldom exceeds 100 millivolts. It is evident that protective films are preserved or formed on metals only when the electrolytes have appropriate characteristics. Thus, a good protecting film is preserved on alumium immersed in solutions of NaCl, HCl and HNO_3 and dissolves in NaOH. Good protecting films are formed on magnesium and manganese in NaOH, for example. It should be noted that the metals of each group immersed in typical electrolytes behave in a similar way in spite of the difference in the absolute values of the potential. In this manner Be resembles Mg, Cr and is somewhat similar to Mo; Fe and Co simulate the performance of Ni, etc.

In a majority of cases, the observed values of the electrode potentials of metals may be explained in the light of a conception embracing microelements of the film-pore type. The protecting film is here regarded as a heterogenous film having many weak spots. In an electrolyte these weak spots are destroyed and are converted into pores. Areas of the metal covered with a continuous protecting film cannot pass metallic ions and cannot, therefore, become anodic areas. When the thickness of the protecting film on a given area is such that a certain amount of electrons can pass through it, the corresponding area may become a cathode, since the cathodic reactions, which merely require a supply of electrons at the external surface, can take place on them. The electrical conductivity of the film plays an important part. A higher conductivity of the film permits an area covered with a heavier layer to act as a cathode. Films which have a very low electrical conductivity, for example those formed by Al_2O_3, MgO, can act as cathodes only when the thickness of the film is very low, of the order 50-100 A. In this light, the surface of a metal may carry three types of areas:

Pores which act as anodic areas.
Areas covered with a sufficiently thin film acting as a cathode.
Areas carrying a heavy film rendering these areas inert.

These areas are shown schematically in Figure 91.

Anodic areas represented by the pores can operate as electrodes of either the first or of the second type, depending on conditions. In an alkaline medium or in a medium containing chloride the pores in a protecting film on copper will act, probably, as electrodes of the second type, while pores in a protecting film on zinc or aluminum should be classified as electrodes of the first type.

The cathodic process on the cathodic areas of the film may vary depending on conditions. It may be associated with the reduction of oxygen to hydroxyl ions when oxygen is present in the solution and when hydrogen ion concentration is not too high. When the pH is low and the concentration of the oxidizing agent is low, a discharge of hydrogen ions by the arriving electrons may take place. Protective films involved exhibit, as is evident, their own values of overvoltage in respect to these processes, i.e., their own polarization characteristics.

As a rule, pores represent but a small portion of the total surface. Even when the specific anodic polarization for a given metal is not high, one has to deal with the possibility of a comparatively steep anodic polarization curve on the Evans' diagram for the film-pore couple since the area of the pores (or anodic areas) is low.

The ohmic resistance of a microelement composed of a film and a pore can be derived from the following considerations:

1. Electrolyte resistance w_p in a pore. Designating electric conductivity of an electrolyte as Z_p, area of a pore F_p and the depth of this pore as L, we can ex-

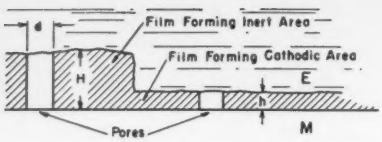


Figure 91—Schematic presentation of different areas on the surface of a metal.

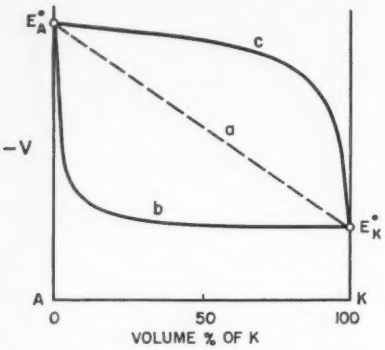


Figure 94—Change of potentials of solid solutions caused by polarization (Akimov and Clark).

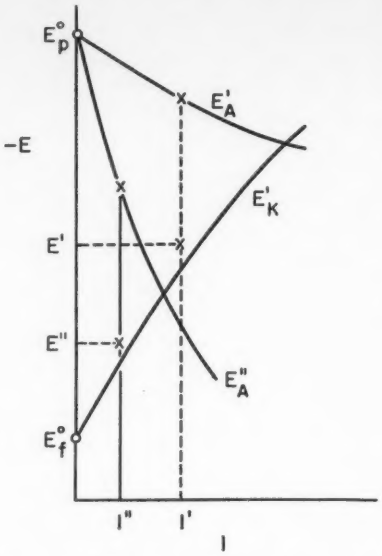


Figure 92—Change of the potential towards positive values with decreasing area of pores (Akimov).

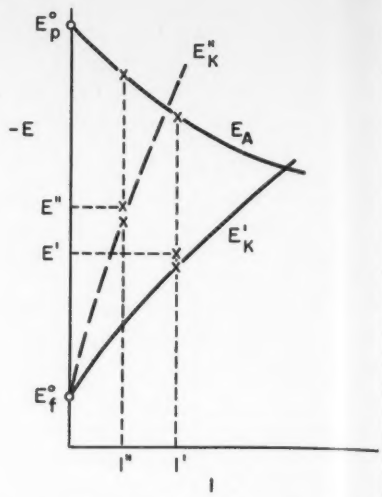


Figure 93—Change of the potential towards negative values with thickening of the film (Akimov).

press the resistance of the electrolyte in the pore as

$$w_p = \frac{L}{F_p Z_p} \qquad (40$$

2. Resistance w_f of the film. Designating electric conductivity of the material forming the film as K_f, area of the film as F_f and its thickness as L, we have

$$w_f = \frac{L}{F_f K_f} \qquad (41$$

3. Resistance of the electrolyte w_s outside of the pore. There are many reasons for assuming this value as much smaller than w_p, because the effective section of the electrolyte outside of the pore is many times greater than the cross section of the pore itself.

We have to account, therefore, only for w_p and w_f. As for any complex electrode, one has to consider here both polarization of anodic and cathodic areas and ohmic resistance. In this light, all conclusions and deductions made already for complex electrodes are applicable. Polarization may be overlooked only when ohmic resistances are very high, which relates mostly to the case of electrolytes having a very low electric conductivity.

One has to examine, in addition to the above, the influence on electrode potential of changes in relative areas of pores, cathodic film and inert film occurring when the thickness of the protecting film increases.

On designating the area of the pores F_p, the area of cathodic film as F_f and the area of insulating film as F_i, we have

$$F_p + F_f + F_i = 1$$

We can assume here that the area of the pores is much smaller than the area of the film.

$$F_p \leqslant F_f + F_i$$

The ohmic resistance of our system is

$$W_p + W_f = W$$

The growth of the film can proceed in different manners. Let us examine two typical cases:

1. F_f and F_i are constant and F_p sharply decreases. The increase of the film area proceeds here largely at the expense of reduced pore area.

As it follows from Figure 92, a decrease of F_p and a corresponding change of anodic polarization curve leads to an increased potential.

2. F_p is constant and F_i increases at the expense of F_f. In this case the growth of the film occurs as a result of further thickening of the thin film on cathodic areas.

The diagram of Figure 93 shows that this increase of film thickness causes a shift of the electrode potential towards more negative values, which appears paradoxical at the first glance. In the diagram of Figure 93, corrosion current corresponding to a given resistance w is I', the total potential located close to the cathodic curve E'_K is E', because the area of the cathode is much greater than the area of the anode (of the K pore). The contraction of the F_f area leads to a steeper polarization curve E'_K with about the same w and to the shifting of the total potential being measured to the point E".

The following examples illustrate this point. A sample of duralumin carrying a natural protecting film had a potential of —0.39 V in a 3% NaCl solution. Then the sample was anodized in a H_2SO_4 solution, as a result of which the total thickness of the protecting film increased about hundredfold, but its electrode potential became simultaneously more negative becoming —0.57 V. This can be explained in the light of film thickening taking place at the expense of thin areas of the film (cathodic areas) with the formation of inert areas. Such an explanation is further supported by a sharp increase in corrosion resistance of the material together with the

rise of the potential. Were this increase of the potential connected with an increasing number of pores, the corrosion resistance has to decrease. Another example can be given in the field of magnesium alloys. Magnesium covered with a natural protective film and immersed in a solution of 0.5 N NaF + 0.001 N NaCl shows a potential of —0.45 V. A strong passivation of magnesium in a mixture of HNO_3 and $K_2Cr_2O_7$ leading to the formation of an artificial protective film leads to a much more negative value of the potential of —1.1 V when the metal is immersed in the same solution.

9. **Electrode Potentials of Solid Solutions and of Intermetallic Compounds.**[19] Electrode potentials are associated principally with the properties of the atoms of a metal and to a much lesser degree with the characteristics of its space lattice. It is well known, for example, that potentials of solid metallic zinc and of liquid zinc amalgam are very close together in spite of the fact that liquid amalgam does not have a definite space lattice. Many metals are capable, at least up to a certain solubility limit, of forming solid solutions. It is important to note that atoms of one component are uniformly distributed among atoms of the other both throughout the body of the solid solution and on its surface. In this case, the structural details of the solid solution, i.e. crystallographic characteristics inherent to different types of solid solutions and to individual solid solutions, are immaterial. The energy of formation of these solid solutions has a pronounced effect. More or less strong bonds are formed among different components during the process of forming solid solutions, so that an expenditure of a certain additional energy is required for separating atoms of solid solutions. Mutual action among atoms associated in the building of solid solutions leads to a certain deformation of atoms and to changes in their properties.

During a study of the relation between electrode potentials and the composition of a solid solution, it is important to know the areas of the surface occupied by each kind of atoms entering the solid solution. On this account, the composition of a solid solution should be given in volume percentages. Once the weight percentage is known, the volume percentage can be determined by means of the formula:

$$\mathrm{Vol_A} = \frac{100\ G_A D_B}{D_B G_A + D_A (100\text{-}G_A)}\ \%\qquad (42$$

where $\mathrm{Vol_A}$ is the volume percentage of the A compound, D_A — specific gravity of the A compound, D_B — specific gravity of the B compound, and G_A — weight percentage of the A compound.

Since there is practically no information on the question of complex alloys, one has to consider at present only binary solid solutions composed of two constituents and in the study of diagrams presenting electrode potentials as a function of composition to isolate carefully all individual factors capable of affecting these potentials. This cannot be done at present for all factors. However, the effect of one very important factor, namely of protective film, may be clarified in a number of cases by measuring electrode potentials both by the usual method and by using continuous abrasion of the fully immersed film by means of a carborundum rod so as to reduce the effect of the protecting film to a minimum. A comparison of electrode potentials measured with and without abrasion of the film gives some idea regarding the effect of the latter.

Diffusion velocity in metallic solid solutions is usually low at room temperature. Any changes in the composition of the metal and its surface layer caused by the effect of electrolyte cannot be restored rapidly by atoms diffusing from the body of the alloy and the electrode potentials of solid solutions must be classified therefore as irreversible.

When it is assumed that the part played by impurities of the alloy is immaterial, that anodic processes are concentrated principally on the atoms of the anodic compound of the solid solution which has a lower value of its electrode potential, that cathodic processes are concentrated on the atoms of the cathodic compound and that many complicating factors can be side-stepped, it can be expected that the values of electrode potentials of solid solutions will arrange themselves on the composition-potential diagram along a straight line connecting points of electrode potentials of pure components, Figure 94a.

Let E_{ss} be the potential of the solid solution. Then

$$E_{ss} = \frac{E_A \cdot F_A + E_K \cdot F_K}{F_A + F_K}\qquad (43$$

where E_A is the potential of the anodic compound, F_A—its area, E_K—the potential of the cathodic compound and F_K its area.

Assuming $F_A + F_K = 1$, one has

$$E_{ss} = E_A F_A + E_K (1 - F_A) = E_K - (E_K - E_A) F_A\qquad (44$$

A study of electrode potentials of solid solutions brings to attention, however, a series of complications which might fully change the expected relation and we shall examine here some of the most important factors.

Properties of each component of a solid solution are modified during the formation of this solution as a function of atomic deformation which is caused by mutual action of different atoms on each other when they are found in a solid solution. On this account, it can be expected that polarization characteristics, both anodic and cathodic, of each component might be changed to some extent. A distortion of polarization characteristics may occur also as a result of the presence in the solution of ions of either one or of both components of the solid solution, so that the destruction of the solid-solution surface might take place during the very first moments of electrolyte action. Irrespective of the true polarization characteristics of the components in solid solution, the polarization of one of the compounds of the solid solution might be much greater than that of the other. When anodic polarization prevails for a given series of solid solutions, the potentials of the solutions are shifted from the straight line *a* towards more positive

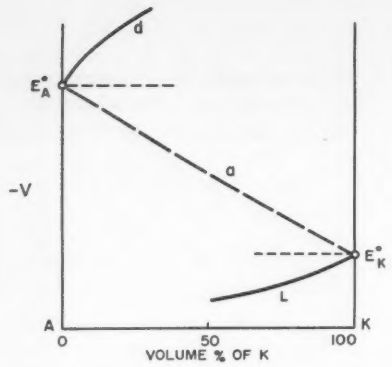


Figure 95—Abnormal change of potentials of a solid solution on reversal of electro-chemical properties of its components (Akimov and Clark).

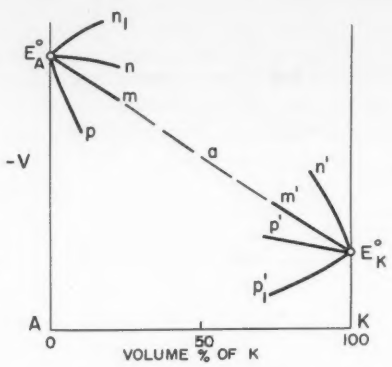


Figure 96—Changes of potentials of a solid solution caused by variations in the properties of the film (Akimov and Clark)

m and m'—Protective properties of films on the solid solution correspond to protective properties of films on components

n, n_1, or n'—Protective properties of films drop with the addition of K compound to A or with addition of A compound to K

p or p', p_1'—Protective properties of films increase with addition of A compound to K

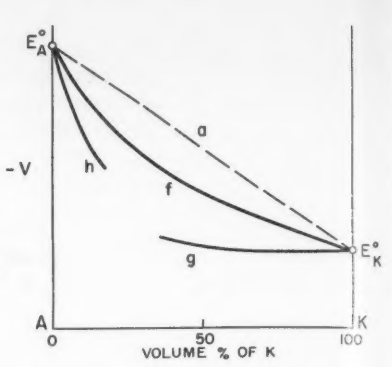


Figure 97—Changes of solid-solution potentials as a function of (f) energy of solid-solution formation, (g) removal of anodic component atoms (h) secondary precipitation of cathode component (Akimov and Clark).

values, as shown by Curve *b* in Figure 94; inversely, a prevailing cathodic polarization renders the potentials of solid solutions more negative, Curve *c*, Figure 94. It is evident that polarization cannot extend the potentials of a solid solution beyond the range of potentials possessed by the components.

It appears that the values of electrode potentials of the components may be more or less distorted on account of atomic deformation in a solid solution. One can hold conceivable the extreme cases when the change of electrode potentials leads to the reversal of electrochemical properties of solid-solution components, i.e. to a cathodic component introduced into a solid solution behaving as an anodic one and vice versa. In the latter case, the curves representing electrode potentials as a function of solid-solution composition become anomalous, Figure 95. An addition of a cathodic component here leads to potential displacement towards negative values, Curve *d*, while an addition of an anodic component shifts the potentials towards the field of more positive ones, Curve L.

Changes in properties of protecting films. An introduction of atoms of a cathodic component into a solid solution in an anodic component and vice versa may change the properties of the protecting film. On this account, the protecting characteristics of a film present on a solid solution can be higher or lower than of the films covering the original metals and, consequently, the electrode potentials of a solid solution can become either more positive or more negative. Figure 96 gives curves showing the variations in potential of a solid-solution electrode as a function of changes in properties of the protecting film, which in turn depend on the composition of the solid solution. In the extreme cases, changing properties of the protecting film can bring the potentials of a solid solution outside the limits of the potentials of its components, Curves P and P′, Figure 96.

The energy of formation of solid solutions and the difficulty associated with the passage of metallic atoms into the solution can shift the potentials of a solid solution towards the positive side as compared with a straight line. This may be considered, however, as another expression of the above-mentioned factor giving the changes in electrochemical properties of components in a solid solution.

Removal of atoms of the anodic component from the surface of a solid solution can take place even during the first moments of the action of the electrolyte. This case relates, apparently, to solid solutions with an excess of the cathodic component. When the atoms of the anodic component are completely removed even from a very thin surface layer and when diffusion velocity is not sufficient to move appreciable quantities of atoms of the anodic component to the surface of metal, the electrode potential of the alloy must be equal to the potential of the cathodic constituent. Atom removal can reduce the potential of a solid solution to the potential of its cathodic component, Figure 97.

Reprecipitation of cathodic constituent. On decomposition of a solid solution having a high concentration of anodic component, both components can pass into solution, because the passage of atoms of the anodic component into solution leads to a complete disintegration of the space lattice of the solid solution. Ions of cathodic component can, however, precipitate from the solution on the cathodic areas (a minimum overvoltage for precipitating a given metal is required) forming a deposit. In this case, an increase of the area of the cathodic component expresses itself by the potential of the solid-solution shifting towards the positive side, Curve *h*, Figure 97. This factor, also considered in a limiting and barely practically possible case, might reduce the potential of a solid solution to that of its cathodic component.

An electrode potential of a solid solution is determined, therefore, by a large number of factors which

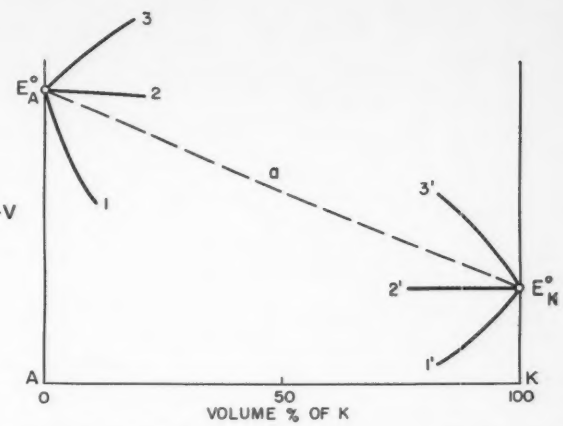
TABLE-11—Solid Solutions Belonging to Three Basic Groups Defined by the Dependence of the Electrode Potential on Composition. (Fig. 98.)

Systems in parentheses were measured after cleaning.

ELECTROLYTE USED				
3% NaCl	0.1*N*HCl	0.1*N*HNO_3[3]	0.1*N*NaOH	———
Type 1				
(Al—Zn) (Al—Cu) Al—Cu (Mg—Sn) (Mg—Al)[2] Mg—Sn (Zn—Ag) Zn—Au	(Al—Zn) (Al—Cu) (Al—Si) Al—Si Al—Cu (Mg—Cd) Mg—Cd (Mg—Zn) Mg—Zn Mg—Sn^2 Zn—Au^2 (Zn—Cu)[2] Zn—Cu (Cu—Ni) Cu—Ni	(Al—Si)[1] (Al—Zn)[2] (Al—Cu) Al—Cu (Mg—Tl) Mg—Tl (Mg—Sn)[3] Mg—Sn^3 (Mg—Zn) Mg—Zn (Mg—Cd) Mg—Cd (Zn—Au)[4] Zn—Au^4 (Zn—Ag) Zn—Ag (Zn—Cu) Zn—Cu	(Al—Zn) Al—Zn Al—Mg Al—Cu (Mg—Sn)[2] (Mg—Al) (Zn—Au) Zn—Au^2	0.1*M* $MgSO_4$ (Mg—Sn) Mg—Sn $NiSO_4$ N—Cu $CuSO_4$ Cu—Au $Ca(OH)_2$ Al—Cu 0.1*M* $MnSO_4$ Mn—Fe
Type 2				
Al—Si Mg—Cd Mg—Al[5] Zn—Al Zn—Cu	Zn—Al (Zn—Ag) (Zn—Ag) Cu—Ag	(Zn—Al) (Cu—Ag) Cu—Ag	(Mg—Tl) (Mg—Cd) (Zn—Cu) Zn—Cu (Cu—Ag)	1*M* $ZnSO_4$ Zn—Au 1*M* $MgSO_4$ Mg—Sn $PbCl_2$ Pb—Bi $MgSO_4$ Mg—Cd[6] 1*N* H_2SO_4 Sn—Sb
Type 3				
(Mg—Tl) Mg—Tl (Mg—Cd) (Mg—Zn)	(Mg—Tl) Mg—Tl Mg—Al[7] Mg—Al[7]	(Mg—Al) Mg—Al	(Mg—Zn)	
Type 1′				
(Al—Mg)	(Al—Li) (Al—Mg) (Cu—Sn)	(Al—Li) (Al—Mg)	(Al—Mg) (Cu—Al) (Cu—Mg)	
Type 2′				
(Al—Li) (Zn—Al) (Cu—Zn)[8] (Cu—Mn)[9] (Cu—Al) (Cu—Ni) (Cu—Be) (Cu—Sn) Cu—Mn Cu—Al Cu—Zn Cu—Sn Cu—Ni Cu—Cd Cu—Be	Al—Mg^9 Al—Li (Zn—Al) (Cu—Zn) (Cu—Mn)[9] (Cu—Al)[9] Cu—Al^9 Cu—Zn Cu—Sn Cu—Cd Cu—Be Cu—Mn^9	Al—Li^9 Al—Zn Zn—Al (Cu—Al) (Cu—Zn) (Cu—Ni) (Cu—Mn) (Cu—Cd) (Cu—Be)[3] Cu—Zn Cu—Al Cu—Mn Cu—Cd Cu—Ni Cu—Sn	(Al—Li) Al—Li (Zn—Al) Zn—Al (Cu—Be) (Cu—Ni)[9] (Cu—Sn) Cu—Cd Cu—Be Cu—Ni^9 Cu—Al^9 Cu—Mn Cu—Zn Cu—Cd	0.1*M* $ZnSO_4$ Ag—Zn 0.5*M* $ZnSO_4$ Fe—Zn $Ca(OH)_2$ Ag—Al $CuSO_4$ Pd—Cu $AgNO_3$ Pd—Ag $NiSO_4$ Cu—Ni $CuSO_4$ $Cu(NO_3)_2$ Au—Cu $Pb(NO_3)_2$ Pd—Pb 1*N*KOH Pb—Sn $Ca(OH)_2$ Cu—Al 1*M* H_2SO_4 Cu—Sn
Type 3′				
Al—Zn Al—Mg Al—Li[8]	Al—Zn Cu—Be[2]	Al—Mg[2]	Cu—Sn	1*M* $ZnSO_4$ Au—Zn $MgSO_4$ Cd—Mg 1*M* $CdSO_4$ Ag—Cd 01*M* $MnSO_4$ Fe—Mn

REMARKS:

1. Almost coinciding with central line *a*
2. Close to central line *a*
3. Slight maximum of the beginning
4. Curve with a minimum
5. Slight minimum
6. Slight downward slope
7. Curve with a maximum
8. Curve intersects straight line *a*
9. Curve with a slight upward slope



Most probable factors which determine: shape of the curves, solid-solution potential, and composition.	Type of the Curve					
	1	2	3	1′	2′	3′
1. Prevalent polarization of the anodic components of the solid solution (+)	●			●	●	
2. Prevalent polarization of the cathodic components of the solid solution (—)		●	●			●
3. Increase of the protecting properties of the film associated with the entry of atoms of the other component (+) into the solid solution	●			●	●	
4. Lowering of the protecting properties of the film associated with the entry of atoms of the other component (—) into the solid solution		●	●			●
5. Reversal of the electrochemical properties of the anode component (+)				●		
6. Reversal of the electrochemical properties of the cathode component (—)		●	●			
7. Removal of the anode component atoms from the surface under the action of electrolyte(+)					●	
8. Secondary precipitation of the cathodic component (—)	●					
9 Energy of solid-solution formation	●			●	●	

Sign (+) indicates that the corresponding factor causes an increase of the potential; sign (—) shows that it decreases the potential.

Figure 98—Basic types of relations between the solid-solution electrode potential and the composition, and the basic factors defining the shape of curves (Akimov and Clark).

are in a complicated inter-relation. On this account, it is not possible at present to predict the electrode potentials of a solid solution based on the potentials of the components.

Possible variations of electrode potentials of a solid solution as related to its composition are shown schematically in Figure 98. In the table under this figure are given factors capable, either alone or in combination, of affecting the course of a given curve.

The previous discussion assumed that impurities present in both cathodic and anodic components and passing into the solid solution do not appreciably affect the value of any electrode potential. There are instances, however, when the influence of impurities must be accounted for.

Cathodic impurities can produce an appreciable anodic polarization of the anodic component causing its potential to become more positive. While addition of a cathodic component leads to a pronounced reduction of the effect exerted by cathodic impurities, for example, by formation of intermetallic compounds with them and a sharp increase of overvoltage on these compounds, it may happen that a definite shift of the potential in the negative direction can take place so that an addition of a cathodic com-

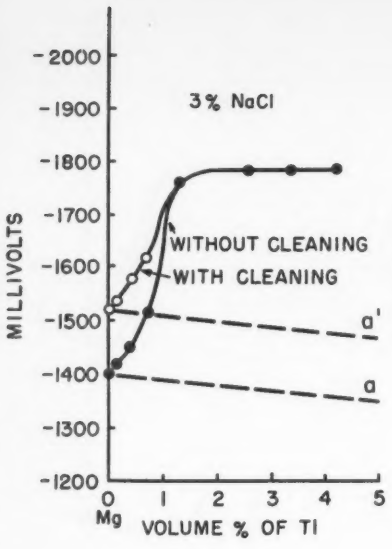


Figure 99—Electrode potentials of Mg-Tl solid solutions in a 3% NaCl solution (Akimov and Clark)
E°Tl—Without cleaning—440 mV
E°Tl—With cleaning—550 mV

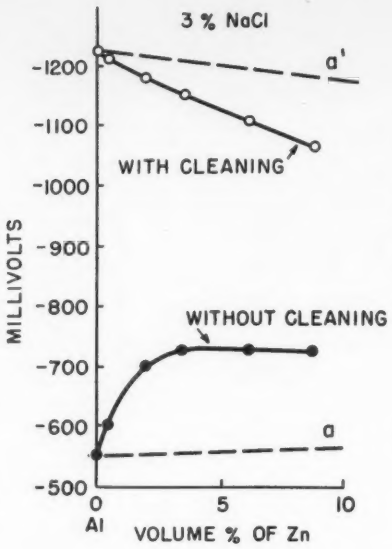


Figure 100—Electrode potentials of Al-Zn solid solutions in a 3% NaCl solution (Akimov and Clark)
E°Zn—Without cleaning—760 mV
E°Zn—With cleaning—820 mV

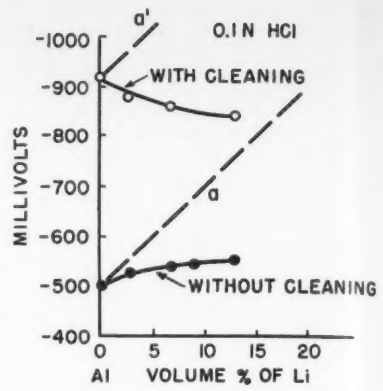


Figure 101—Electrode potentials of Al-Li solid solutions in a 0.1N HCl solution (Akimov and Clark).

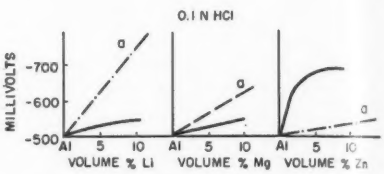


Figure 102—Electrode potentials of Al-Li, Al-Mg and Al-Zn solid solutions (Without Cleaning) (Akimov and Clark).

ponent results actually in the solid solution becoming more noble and in a reduced corrosion velocity. This is another explanation of the abnormal course of Curve 3, besides the one given in the table under Figure 98.

Table 11 presents basic data related to electrode potentials of solid solutions in typical electrolytes. Corresponding measurements were conducted with and without the use of cleaning the metal surface under the surface of the electrolyte. Systems investigated employing cleaning are placed in parentheses.

All systems investigated are grouped in Table 11 in a series corresponding to the basic types of relations between the electrode potentials and the composition of solid solution, as shown in Figure 98. A number of important deductions can be made from these data.

First, it appears that all six basic types really exist, though the frequency of their appearance varies. Solid solutions having a predominance of anodic component are most frequently associated with Type 1, corresponding to a normal potential increase. Type 2 (a very slight potential change on addition of a cathodic component to an anodic matrix) occurs much less frequently, and finally, Type 3 characterized by abnormal potential drop after the addition of a cathodic component can be observed even less frequently. It should be mentioned that only solid solutions having a magnesium base belong to the third type.

For solid solutions having a predominance of cathodic component, Type 2′ (retention of the electrode potential of the cathodic component) is most often encountered. This indicates a pronounced effect for this group of solid solutions of one factor, the elimination from the surface of the solid solution of an anodic component caused by the action of electrolyte.

The normal 3′ type associated with the lowering of potentials on introduction of an anodic component occurs but seldom in this series of solid solutions. Type 1′ marked by an abnormal potential increase on addition of an anodic component to a solid solution also occurs rather seldom. It may be noted here that, unexpectedly, only potentials measured using cleaning, in other words, when the influence of the protective film is reduced to a minimum, belong to this type.

Experimental data indicate that, in a number of cases, the relation is even more complex when curves are produced having maxima and minima, or curves which intersect the central *a* line. There are but very few cases when the curve representing the relation of potential to the composition coincides or passes very closely to the central *a* line. A perusal of the tables demonstrates that the type of the curve is mostly defined by the solid solution itself. A number of examples can be found, however, pointing at the important effect of the electrolyte, causing the same system of solid solutions to fall into different groups, once the electrolyte is changed. As an example may be given the Mg-Tl system which in 3% NaCl, 0.1 N HCl, or 1 N $MgSO_4$ solutions belongs to Type 3, Figure 99, in a 0.1 N NaOH solution to Type 2, and in a 0.1 N HNO_3 solution to Type 1. The system Cu-Sn, which was investigated using cleaning, belongs to Type 2 when immersed in a 3% NaCl, 0.1 N HNO_3, 1 N H_2SO_4 and 0.1 N NaOH, but passes to the Type 1 when tested in a 0.1 N HCl solution.

The part played by protective films appears to be quite important. So, for example, the system Al-Mg is related to Type 2′ or 3′ when 3% NaCl, 0.1 N HCl

and 0.1 N HNO_3 electrolytes are used but shifts to Type 1 when cleaning is employed during testing. When cleaning changes pronouncedly, the electrode potentials of the components themselves, which is characteristic of the Group A and the transition group of metals, measurements with cleaning and without cleaning really force one to deal with two entirely different systems. Figure 100 shows the results obtained during measuring potentials of solid solutions of the Al-Zn system in a 3% NaCl solution. On conducting these measurements without cleaning, the values recorded were $E°_{Al} = -550$ mV and $E°_{Zn} = -760$ mV, i.e. $E°_{Al}$ is cathodic to $E°_{Zn}$, which indicates that these solid solutions are related to a group with a predominant cathodic component. The middle Curve *a* rises, therefore, with an increasing Zn content in the alloy. Experimental data show that the curve for the Al-Zn alloy determined without cleaning sharply differs from the straight line *a* rising steeply at the beginning into the region of negative values. This system belongs, therefore, to the normal 3′ type. Corresponding measurements conducted with the cleaning of the electrodes indicate that the potential of aluminum becomes less noble until it reaches $E°_{Al} = -1220$ mV, while the potential of zinc decreases much less and reaches only $E°_{Zn} = -820$ mV. In this case the relations are changed so that $E°_{Zn}$ becomes greater than $E°_{Al}$ and the system belongs to a group of solid solutions with a predominant anodic compound. The curve for the Al-Zn system belongs to the normal Type 1.

This influence of the film is less noticeable on solid solutions having a magnesium and zinc base, because cleaning has no appreciable effect on the magnitude of electrolytic potentials even on pure Mg and Zn components in a majority of electrolytes.

Figure 101 gives a remarkable case of the Al-Li system. In spite of the strongly negative potential of lithium, equal to —3000 mV, and the absence of any protective films on this metal, caused by high solubility of LiOH in water, the entrance of lithium into a solid solution with aluminum leads either to a slight lowering of the potential observed when the cleaning is employed or to a potential rise when cleaning is not employed. These data directly point out the impossibility of explaining the abnormal behavior of Al-Li alloys in the light of changing properties of the protecting film. The reversal of electrochemical properties of lithium when present in a solid solution appears to be the most probable explanation.

A comparison of the influence of different components on potentials of a solid solution fails to point out any relation between the potential of the component and the effect produced by this component even within the range of a single type of solid solutions. Figure 102 presents the influence of three components, namely lithium, magnesium and zinc, on the potential of a corresponding solid solution with aluminum, determined without cleaning. It is apparent that zinc shifts the potential of the solid solution to the negative side the most, and lithium the least. This effect is in the reverse relation to the values of potentials of these three metals. Many other examples of the same type can be given.

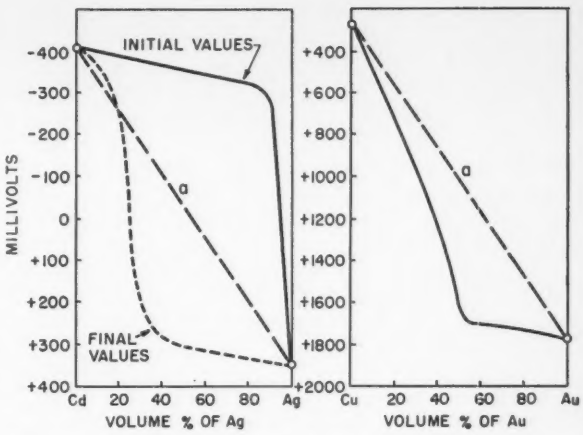


Figure 103—(Left) Electrode potentials of Cd-Ag solid solutions in a 1N $CdSO_4$ solution.

Figure 104—(Right) Electrode potentials of Cu-Au solid solutions in a 1N $CuSO_4$ solution.

TABLE 12—Electrode Potentials of Intermetallic Compounds in a 3% Sodium Chloride Solution (Akimov and Oleshko)

INTERMETALLIC COMPOUND	ELECTRODE POTENTIALS	
	After 5 Minutes	After 10 Minutes
$CuAl_2$	—0.372	—0.371
$FeAl_3$	—0.14	—0.209
Mn Al	—0.18	—0.604
$NiAl_3$	—0.468	—0.467
Mg_2S_2	—1.268	—1.023

Figure 103 presents electrode potentials of solid solutions of the Cd-Ag system in 1 N $CdSO_4$ solution. The solid curve, corresponding to the original values of the potentials, shows that a silver addition to cadmium slowly displaces the potential towards more positive values. Addition of cadmium to silver, on the other hand, rapidly lowers the potential of the alloy. This shape of curve can be explained as a function of the preponderant polarization of the cathodic component of the solid solution. However, after a certain time, the curve is shifted steeply towards positive values, and its character changes pronouncedly, as is shown with a dotted line in the diagram. As a most probable explanation may be offered the theory that at this moment the major effect is caused by the elimination of the atoms of the anodic components from the surface of the alloy under the influence of the solution and a sharp increase in the polarization of the anodic component associated with it.

Figure 104 shows the curve of electrode potentials of the system Cu-Au. The whole curve occupies a much more positive position than the middle straight line *a*, and its shape again corresponds to a strong polarization of the anodic component. Curves of a similar type can be observed for a series of other continuous solid solutions of electropositive metals. It should be noted that often, but not always, the break of the curve lies at around 50 volume percent.

For the system
- Cu — Pd in $CuSo_4$ 53-58 vol. percent
- Ag — Pd in $AgNO_3$ 49 vol. percent
- Cu — Au in $CuSO_4$ 50 vol. percent
- Cd — Ag in $CdSO_4$ 45-50 vol. percent

Let us pass now to the question of electrode potentials of intermetallic compounds. It can be expected that the laws governing them are similar to those described for solid solutions. It is probable that the part played by the deformation of atoms during formation of intermetallic compounds and a corresponding change of the properties of the metallic atoms as well as the energy of formation of these compounds are much higher than in the case of solid solutions. However, the experimental data available on the subject are quite limited. We can present now only the data on the electrode potentials of intermetallic compounds having an aluminum base. These were measured on single crystals[20] and are, therefore, more reliable than the previous data, Table 12.

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End of Part 2 of 2 Parts

Any discussions of this article not published above will appear in the June, 1956 issue.

Test Methods to Determine The Resistance of an Insulating Joint*

By E. T. PEARSON

Abstract

Test methods for determining the resistance of an insulating joint under a number of conditions are discussed. Consideration is given to the purposes for which insulating joints are commonly used. A detailed study is made of the problem of determining the true resistance of an insulating joint installed between two buried structures when a direct, accurate current measurement is not possible on either structure at the insulating point. The Parallel computation, Delta computation and the Null circuit methods are discussed in connection with this problem.

Introduction

AN INSULATING joint is primarily a control measure. Its purpose is to stop or limit the flow of an electrical current along a pipe or cable sheath. Theoretically it should have an infinite resistance value; any lesser value desired could then be obtained by a shunting resistance placed across the joint. In practice, the resistance of any insulating joint installed between two buried structures automatically is paralleled by the resistance of the path through ground, which is the sum of the two structure-to-ground resistances, as shown in Figure 1A.

A current I, flowing on Pipe A and approaching an insulating joint, will divide into two components which will be known as I_J and I_G. The component I_J continues on through the true resistance R_J of the insulating joint. The component I_G flows to ground through the structure-to-ground resistance R_A of Pipe A, then through the ground and back to Pipe B through its structure-to-ground resistance R_B. At that point it joins with the other component I_J to again become the total current I. The electrical schematic of these resistances is shown in Figure 1B.

From the viewpoint of the total current I, the resistance it will encounter in getting past the insulating joint is the resistance equivalent to the two parallel paths, which can be computed as the product of the resistances in each path divided by the sum of the resistances in each path. Thus the *apparent* resistance of the insulating joint to current I is:

$$\text{App. } R_J = \frac{R_J\,(R_A + R_B)}{R_J + R_A + R_B}$$

It is evident that to structures with ground resistances in the order of tenths of an ohm, a true insulating joint resistance in the order of several ohms would form an effective barrier for current control. However, with structures having ground resistances in the hundreds of ohms, as can be the case with well-coated pipes, an insulating joint with a few ohms true resistance would look like a short-circuit to the current I. In this case a true insulating joint resistance in the order of thousands of ohms would be required as an effective barrier. This explains why it is sometimes difficult to answer the question, "Now what do you consider that the resistance of a good insulating joint should be?"

General Applications

Three general applications and reasons for the use of this control measure are illustrated by Figures

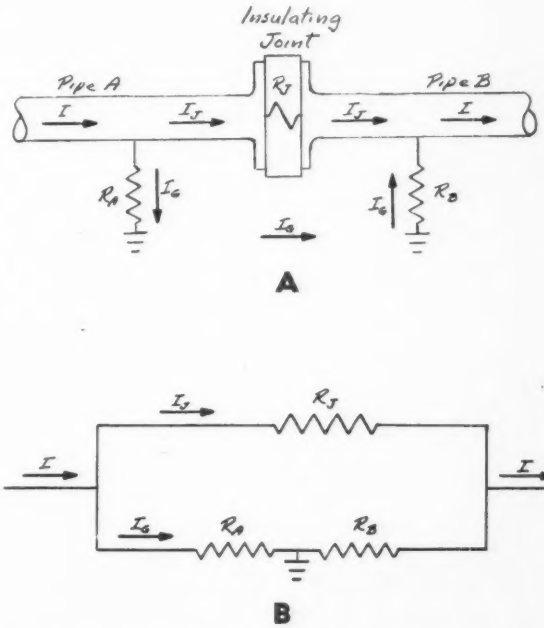

Figure 1—Top drawing (Figure 1A) shows how current passes through and around an insulating joint. In Figure 1B the current is shown splitting up into two components.

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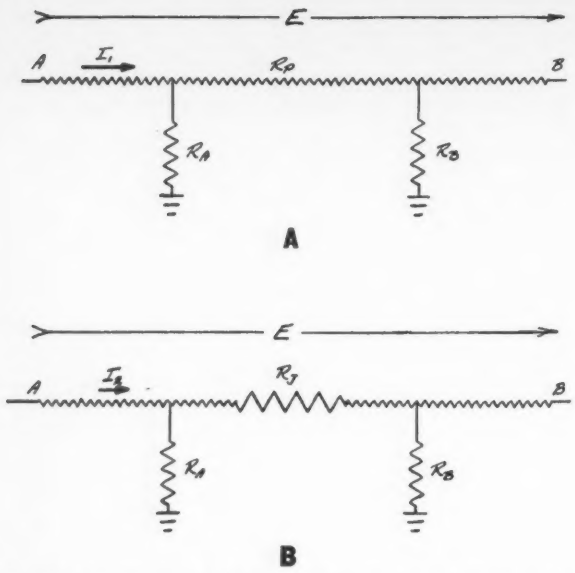


Figure 2—In upper drawing, Rp is much lower than the combined ground resistances. In lower drawing, insulating joint has a relatively high resistance.

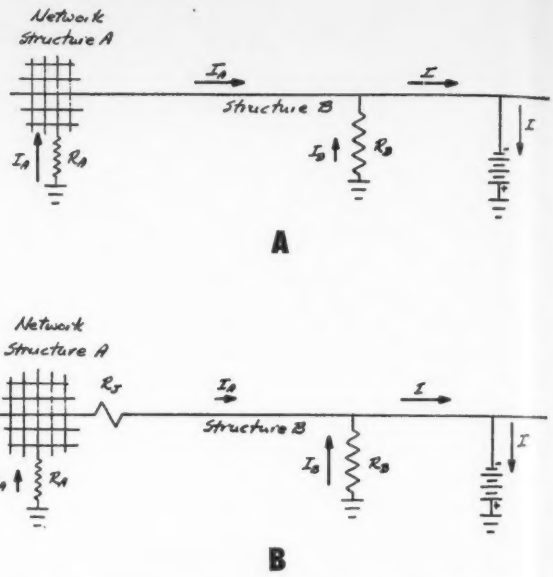


Figure 4—In top drawing a relatively high resistance-to-ground structure is shown connected to a low resistance-to-ground structure. In lower drawing an insulating joint is added.

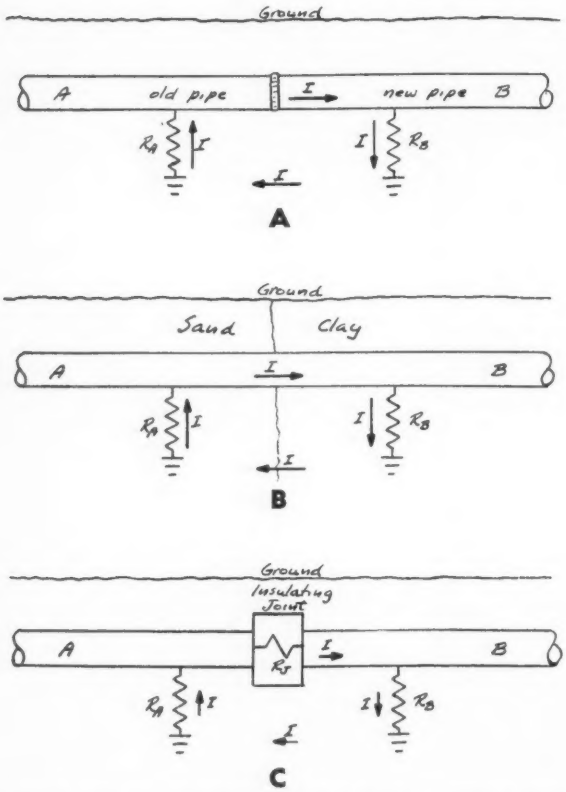


Figure 3—Top drawing shows current flow in an arrangement where two dissimilar metals are coupled together. Middle drawing shows current flow through two unlike soils. In lower drawing an insulating joint is inserted in the current path between two structures.

2, 3 and 4. First, as shown in Figure 2A, if a certain potential value caused by a stray current or earth gradient is impressed on a pipe, making point A some voltage E positive to point B, the current flow I_1 would be governed mostly by the low resistance R_P of the continuous metallic structure. This is because R_P is very much lower in resistance than the combined ground resistances R_A and R_B with which it is in parallel. For all practical purposes, the current flow on the pipes would be given by:

$$I_1 = \frac{E}{R_P}$$

Now, if as shown in Figure 2B, a relatively high resistance insulating joint is installed between the points A and B, with the driving voltage E remaining unchanged, the current flow I_2 will change to:

$$I_2 = \frac{E}{\text{Apparent } R_J}$$

That the Apparent R_J can be made large with respect to R_A and R_B was shown earlier, and in themselves R_A and R_B are usually much larger than the metallic resistance R_P. R_P, being small, is a negligible part of the true R_J. The result is that the current I_2 now flowing on the structure as a result of the voltage E is reduced to a small fraction of I_1.

Dissimilar Metals

The second application of the use of an insulating joint is illustrated by Figure 3. As shown in Figure 3A, two dissimilar metals coupled together in homogeneous earth form a cell, producing a voltage such that a current I flows from the anodic pipe B to ground through resistance R_B, then to cathodic pipe A through its resistance R_A. It completes the circuit through the metallic junction between the pipes.

A similar cell and corroding current can be set up by a continuous metallic structure through two unlike soils, as is illustrated in Figure 3B. In either

case, the corroding current is limited only by the cell potential and the sum of the structure-to-ground resistances:

$$I = \frac{E\ (couple)}{R_A + R_B}$$

If, however, an insulating joint is inserted in the current path between the two structures as shown in Figure 3C, its resistance is added to the denominator in the above equation, and the corroding current I becomes:

$$I = \frac{E\ (couple)}{R_A + R_B + R_J}$$

a value which becomes negligible if R_J is made large.

Third Application

The third common application of insulating joints is illustrated in Figure 4. If, as is shown on Figure 4A, a relatively high resistance-to-ground structure B is connected to a low resistance-to-ground structure A, and a cathodic protection current I is impressed on the earth, the total current I will divide into components I_A and I_B which are in inverse proportion to the resistances:

$$\frac{I_B}{I_A} = \frac{R_A}{R_B}$$

or:

$$I_A = I_B \times \frac{R_B}{R_A}$$

Supposing a protective current of one ampere were required through resistance R_B, and that the relative resistances were $R_A = 1$ ohm, $R_B = 9$ ohms. From the formulas, $I_A = 1 \times \frac{9}{1} = 9$ amperes, and a total of 10 amperes would have to be supplied at the cathodic protection unit to make one ampere effective on Structure B.

If, however, an insulating joint with resistance $R_J = 89$ ohms is installed between the structures, (see Figure 4B) the formulas become:

$$\frac{I_B}{I_A} = \frac{R_A + R_J}{R_B}$$

or:

$$I_A = I_B \times \frac{R_B}{R_A + R_J}$$

Then for the figures given:

$$I_A = 1 \times \frac{9}{1 + 89} = 0.1 \text{ amp}$$

and the cathodic protection unit has to supply only 1.1 amperes to provide one ampere of protection effective on Structure B.

As R_J is made larger in relation to R_A and R_B, the protective current I_B approaches the total current I, and the wasted current I_A is reduced to a minimum.

Practical Applications

In practical applications on underground cable systems, the use of insulating joints is confined almost wholly to the examples of Figures 3 and 4. They are used in such cases to break the dissimilar metal couple between the anodic lead cable sheath and the cathodic copper station ground, and then to provide protective current to the relatively high resistance cable sheaths without returning a prohibitive amount of current through the very low resistance station ground structure.

Stray Current Values

The insulating joint application shown in Figure 2 is used principally to reduce the stray current values on long pipe lines. The applications of Figure 3 are valid where sections of mains are replaced with new pipe, particularly new coated main in an area of old bare mains, or in long pipe lines traversing alternate clay or swamp and sandy soils.

The principles illustrated in Figure 4 are applicable to pipe lines having low resistance river crossings, services or cross-connections with other utilities, or to the isolation of any section for the economical use of protective current.

The tester determining the resistance of an insulating joint should have some concept of the reason for its installation, since the resistance value required may vary with the physical characteristics and circuits of the two structures it separates. Indeed, in many cases, particularly of insulating joints in cable sheaths, no resistance value other than "bad" or "good" is needed; either it will pass a measurable current or it will not. The construction of a porcelain or fiber insulating joint in lead sheathed cable is such that an intermediate degree of effectiveness is unlikely. Similarly, small Dresser insulating couplings are not usually measured for a definite resistance value; they are either insulating or non-insulating.

Definite Resistance Value

However, in the case of larger couplings or insulating flanges, where the effect of moisture penetration in the component parts can result in a great variation of effective resistance, it is considered advisable to obtain a definite resistance value. This value is useful first as a check on the insulating flange as constructed. It can be compared with subsequent values to show deterioration should such occur, it is a figure needed to compute a stray or impressed current flow through the joint with a simple measure of the voltage across the flange, and it becomes a network constant for use in the generally accepted method of network analysis of cathodic protection, interference current or drainage bond problems.

Determination of Resistance

With an understanding of these general principles as a background, it is possible to proceed to the

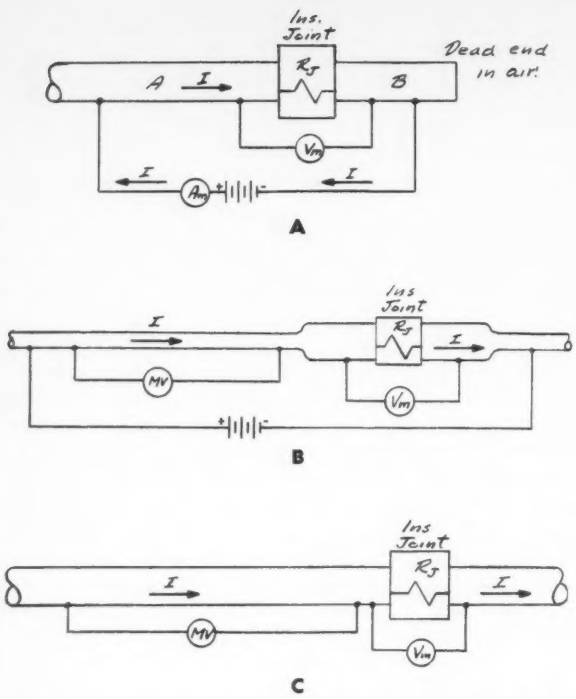


Figure 5—Three ways of measuring the resistance of an insulating joint.

various methods applicable to the determination of the resistance of an insulating joint.

Fundamentally, the resistance (in ohms) equals the voltage measured across the joint (in volts) divided by the current flow directly through the joint (in amperes); in other words, Ohm's Law. Because of the fact that two pairs of leads are usually provided for testing, one pair attached to each structure adjoining the insulating joint, it is always easy to measure the voltage or impress a test current across the joint. The usually difficult task is to measure the current actually flowing through the insulating joint. In three instances, typified by Figures 5A, 5B and 5C, this measurement can be made easily, with a fair degree of accuracy.

Insulating Flange

Figure 5A illustrates a condition where an insulating flange has been assembled, but Pipe B on the right hand side is neither continuous nor backfilled. In other words, there is no ground path for current flow in parallel with the insulating flange resistance. With a potential applied by a battery, a direct reading of the ammeter and voltmeter placed as shown will give the true insulating joint resistance R_J. A typical example might be a current reading of 1.0 ma with a voltage of 6.0 volts, giving the insulating flange resistance as:

$$R_J = \frac{6.0}{.001} = 6{,}000 \text{ ohms}$$

Any direct reading ohmmeter or megger also can be used in this circuit to give the true resistance R_J.

Cable Sheaths

The same battery and voltage circuit, but slightly different current measurement, is illustrated in Figure 5B. This circuit is applicable principally to insulating joints in cable sheaths, where there is room in the manhole to obtain a current measurement by a millivolt drop on the cable sheath between the battery connection and the insulating joint. The millivolt measurement is converted to amperes I of current flow on the sheath and the same simple resistance formula applies.

The parallel ground path outside the manhole is not important because the measured current I can flow nowhere but through the insulating joint. It is the usual practice to dispense with the voltage reading; zero current I means a good insulating joint, any measurable current I means a bad insulating joint.

Figure 5C is essentially the same as Figure 5B, but applies more particularly to pipe lines where a calibrated current drop measurement has been installed adjacent to an insulating flange. The usual procedure, if there is some stray current flow, is to take values of the current I, as translated from millivoltmeter readings on the calibrated current drop, simultaneously with values of the potential E across the insulating flange, as read on the voltmeter Vm.

The slope of a curve plotted with E as ordinates and I as abscissae is the insulating joint resistance R_J. If stray current is too small to be measurable, a battery circuit identical to that shown in Figure 5B, with the connection past the remote current drop wire, can be set up and readings of I and E taken with increments of battery current. It is presumed that the pipe coating is good enough so that no appreciable current is lost to or gained from earth within the length of the millivolt drop connections on the pipe. With the battery circuit added, the parallel ground path beyond this area, as mentioned in Figure 5B, again is not important. This is because all of the measured current I must flow through the insulating flange to cause the IR_J potential to equal E.

True Resistance of Insulating Joint

At this point there is still the problem of determining the true resistance of an insulating joint installed between two buried structures, with no direct, accurate current measurement possible on either structure at the insulating joint. There are three possible methods of solution. The first two involve computations using intermediate measurements which are more or less familiar in corrosion work and the third involves a null circuit recently proposed by J. P. Kisch of the Public Service Testing Laboratory.

The three methods will be designated as follows:

Method 1—Parallel computation
Method 2—Delta computation
Method 3—Null circuit

The fundamental circuit is, of course, common to all three methods. Because the structures adjacent to the insulating joint are buried, each has a definite resistance to ground. The electrical schematic of the

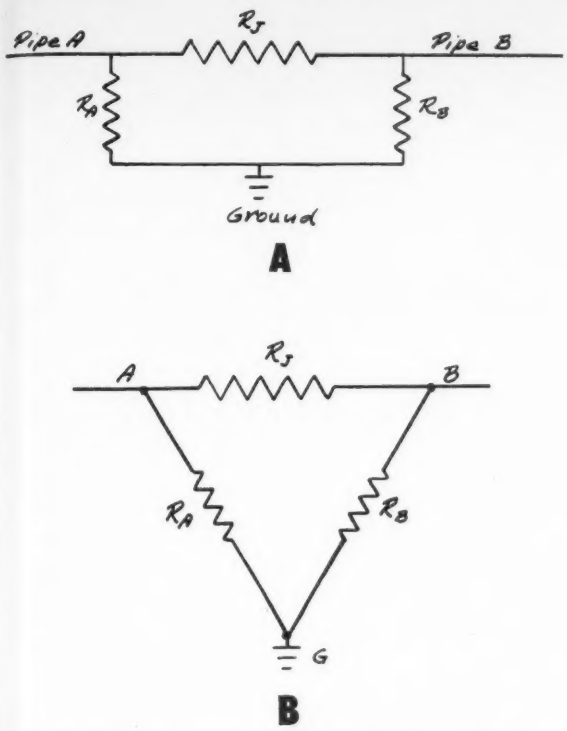


Figure 6—Top drawing shows an electrical schematic of three resistances. In lower figure the delta arrangement is used.

three resistances is shown in Figure 6A, where R_J is the true or required insulating joint resistance, and R_A and R_B are respectively the true resistances to ground of the two buried structures, Pipe A and Pipe B. Inasmuch as the earth or ground G is the common junction point between R_A and R_B, it may be easier to visualize the circuit as a delta arrangement of the three resistances, as shown in Figure 6B.

In order to use either Method 1 or Method 2, the intermediate step of obtaining three definite ohmic values for the apparent resistances of R_J, R_A and R_B must be taken. The measurement of the apparent insulating joint resistance, App. R_J, is illustrated in Figure 7.

Apparent Resistance to Ground

Similar connections are established to obtain the apparent resistance to ground of Pipe A, App. R_A, as shown in Figure 8. A remote driven rod is used for the battery connection to ground. A copper-sulfate reference cell, remote from both the pipe and driven rod, is used to measure the potential of Pipe A to ground, which is the voltage across the resistance R_A.

For the apparent resistance to ground of Pipe B, App. R_B, the battery and voltmeter connections are moved from Pipe A to Pipe B, and the same procedure as shown in Figure 8 followed.

At this point it might be well to emphasize why these three measured resistance values are "apparent" rather than "true." Reference should be made again to Figure 7. As noted by the arrows, the

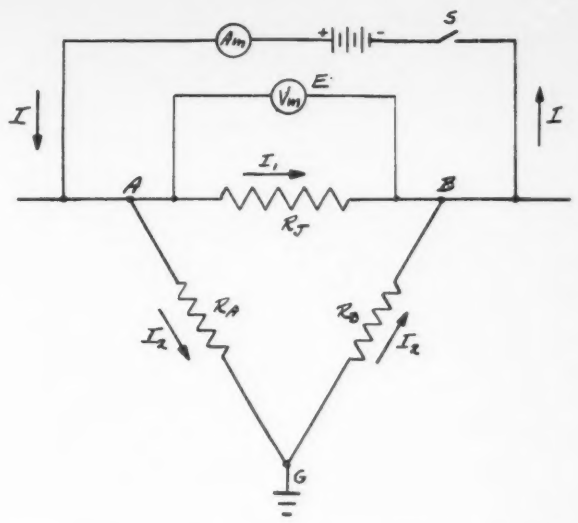


Figure 7—Apparent resistance of an insulating joint. App. $R_J = \frac{\Delta E}{\Delta I}$; E = volts, read on Vm; I = amperes, read on Am; Δ = reading with S closed minus reading with S open.

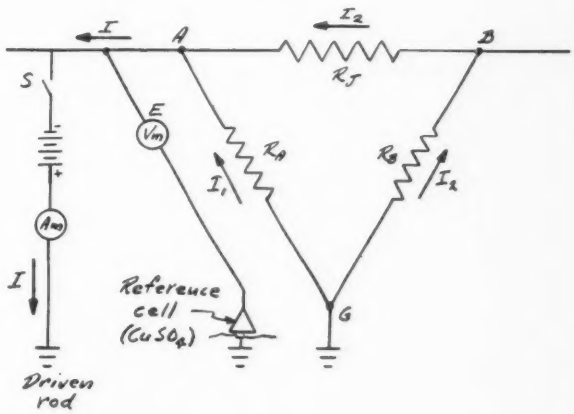


Figure 8—Apparent resistance to ground of structure A. App. $R_A = \frac{\Delta E}{\Delta I}$; E = volts, read on Vm; I = amperes, read on Am; Δ = reading with S closed minus reading with S open.

total measured battery current I divides in some unknown proportion into the components I_1 and I_2, I_1 flowing through R_J and I_2 flowing to ground through R_A and from ground to Pipe B through R_B. The true value of R_J would be given by:

$$R_J = \frac{\Delta E}{\Delta I_1}$$

but since I_1 is unknown, only an apparent resistance can be measured.

$$\text{App. } R_J = \frac{\Delta E}{\Delta(I_1 + I_2)} = \frac{\Delta E}{\Delta I}$$

A study of Figure 8 shows that a similar current division takes place, I_1 now flowing only through R_A and I_2 flowing through both R_B and R_J before rejoining with I_1 to form the total current I. Again, the true R_A would be $\Delta E/\Delta I_1$, but the measured

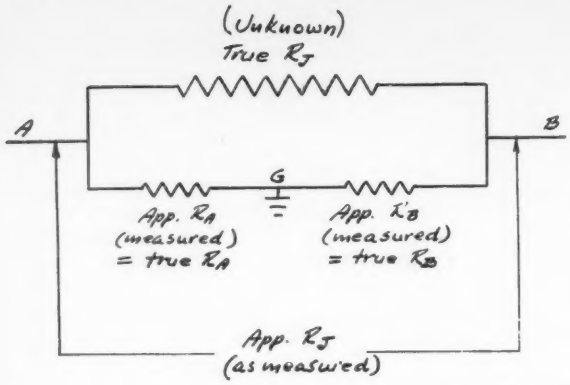


Figure 9—Parallel computation (method 1). App. $R_J = \frac{R_J \times (R_A + R_B)}{R_J + R_A + R_B}$

Solving: True $R_J = \frac{(R_A + R_B) \times \text{App. } R_J}{(R_A + R_B) - \text{App. } R_J}$

value is obtained from $\Delta E/\Delta(I_1 + I_2)$ or $\Delta E/\Delta I$, which is an apparent R_A or R_B, as the case may be.

Having determined these three intermediate apparent resistance values, the true insulating joint resistance R_J can be computed by Method 2, or in certain cases by Method 1.

Parallel Computation

The parallel computation, Method 1, is applicable only when the resistance R_J of the insulating joint is so high that the current division shown in Figure 8 is negligible, and the measured apparent resistance values of R_A and R_B are in fact the true values within the accuracy of measurement. In this case the value of App. R_J, measured as shown in Figure 7, would closely approach the sum of R_A and R_B. It would become in effect a resistance value equivalent to and resulting from an unknown resistance R_J in parallel with two known resistances R_A and R_B, which are in series. The solution by the parallel formula in this case is shown in Figure 9.

Obviously, if the measured App. R_J equals the sum of R_A and R_B, the true insulating joint resistance R_J is infinite. If the App. R_J as measured is greater than $R_A + R_B$, there has been a mistake in one or more of the measurements. An actual case where this method was used to check an insulating joint at a tie point between a bare and a coated main had the following values:

App. R_A = .24 ohms (bare main)
App. R_B = 100 ohms (coated main)
App. R_J = 99.0 ohms

$$\text{Solving } R_J = \frac{(100 + 0.24) \times 99}{100 + 0.24 - 99} = \frac{9924}{1.24} = 8000 \text{ ohms}$$

The same insulating joint had been checked on the previous day before the connection to the coated main was completed, with the direct measurement method shown in Figure 5A. The result at that time was 8200 ohms, showing that Method 1 could give a very close check.

Method 2

Where the three apparent resistance values measured are all in the same order of magnitude, indicating an appreciable current division, the computation of Method 2 can be applied. This method has been well presented in two papers,[1,2] and a simplified computation was presented in another paper.[3] A brief review of the simplified method of delta computation may be in order, using the nomenclature followed in this paper.

The three measured apparent resistances can be called A, B and C, or:

App. R_A = A
App. R_B = B
App. R_J = C

From these values, three computation values of x, y and z are then found from the following formulas:

$$x = \frac{-A + B + C}{2}$$

$$y = \frac{A - B + C}{2}$$

$$z = \frac{A + B - C}{2}$$

A constant K is then determined as:

$$K = xy + xz + yz$$

The three true resistances are then computed as:

$$R_A = \frac{K}{x} \text{ ohms}$$

$$R_B = \frac{K}{y} \text{ ohms}$$

$$R_J = \frac{K}{z} \text{ ohms}$$

Using the same figures given as an example in the papers mentioned, the delta computation works out as follows:

App. R_A = 30 ohms = A
App. R_B = 50 ohms = B
App. R_J = 70 ohms = C

$$x = \frac{-30 + 50 + 70}{2} = 45$$

$$y = \frac{30 - 50 + 70}{2} = 25$$

$$z = \frac{30 + 50 - 70}{2} = 5$$

$$K = 45 \times 25 + 45 \times 5 + 25 \times 5 = 1475$$

$$R_A = \frac{1475}{45} = 32.7 \text{ ohms}$$

$$R_B = \frac{1475}{25} = 59.0 \text{ ohms}$$

$$R_J = \frac{1475}{5} = 295 \text{ ohms}$$

Two points should be noted about the delta computation method. First, the measured apparent resistances must have values such that the sum of any two is larger than the third. With dissimilar structures, it is not always possible to arrive at values with sufficient accuracy to fulfill this requirement, as was shown with the values quoted as the example for Method 1. Second, the higher the true resistance value of the insulating joint, the more critical the accuracy of the last significant figure in the intermediate measurement becomes.

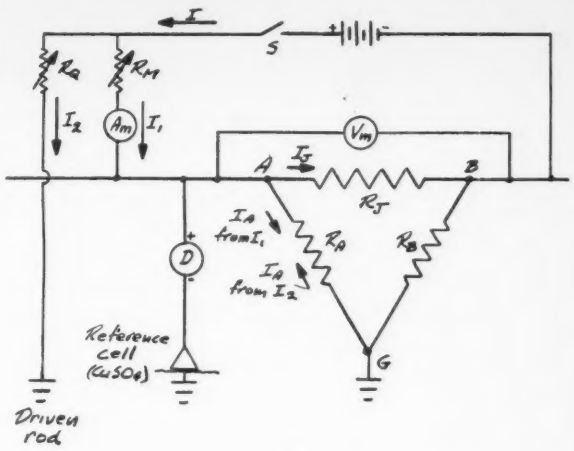
Method 3

It has been found that Method 3, the Null Circuit, is becoming increasingly useful. This is because it is not necessary to know the physical details of the adjoining structures before testing the insulating joint, nor is it necessary to obtain accurate values of the three apparent resistances. The circuit used is in effect a combination of those shown in Figures 7 and 8, with variable resistances R_M and R_Q added to control the two current circuits.

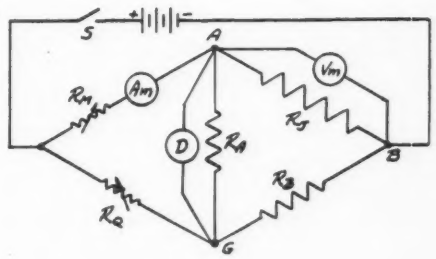
The necessary components and connections are shown in Figure 10A, and the equivalent electrical circuit is drawn as Figure 10B.

As may be noted, the method reduces to the familiar Wheatstone bridge circuit. The principle of operation is as follows: Battery test current I, controlled by the switch S, is simultaneously applied as two controlled components I_1 and I_2 to Pipe A and ground G, with the battery negative connected to Pipe B. As shown in the previous explanation of "apparent" resistances, the component I_1 can again divide in unknown proportions, into a part I_J flowing through R_J and a part I_A flowing to ground through R_A. A measure of this second portion, flowing from A to G, is given by the reading on voltmeter D, which shows the change in potential of Pipe A to ground, or I_AR_A.

But at the same time, the other battery current component I_2, applied to G through a driven rod, can also divide into two parts, one of which returns to the battery negative at B via R_A and R_J. This part of I_2, if applied independently, would show a reading of opposite sign on voltmeter D, as a measure of I_AR_A flowing from G to A.



A



B

Figure 10—Null circuit (method 3). Necessary components and connections are shown in upper drawing. The equivalent electrical circuit is shown in lower drawing.

Zero Deflection

With the two currents applied simultaneously, they are controlled to give a zero deflection or null reading on the voltmeter D. This indicates a condition of zero current flow through resistance R_A, at which time the only current appearing on ammeter Am is I_J, flowing directly through the resistance R_J of the insulating joint.

A second voltmeter Vm is read to give the voltage E_J across the resistance R_J, and the direct value of the required insulating joint resistance is given by:

$$R_J = \frac{E_J}{I_J} \text{ ohms}$$

R_J also can be obtained by reversing the battery and metering connections at A and B, thus making R_B the nulled resistance. It has been standard practice to obtain these two values of R_J, which usually agree within ten percent, and to use the average as a final figure.

It also should be noted that if the values of R_M and R_Q are measured at the null point, the proportion

$$\frac{R_M}{R_Q} = \frac{R_J}{R_B}$$

holds true, and affords a check on the computed resistance value. Of course, the value of R_Q must include the structure-to-ground resistance of the driven rod.

It also is possible to obtain a true R_A or R_B by changing connections to effect a 120 degree rotation of the triangle of resistances R_A, R_B and R_J in the electrical schematic, using either R_J or the other structure as the nulled resistance.

No definite figures are included as examples, as the computation required is only a simple division. But values of different insulating joint resistances ranging from less than one ohm to several thousand ohms have been checked with this circuit, and in many instances rechecked as correct by some of the other methods outlined in this paper.

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The Corrosion Behavior of Aluminum*

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Abstract

The practical corrosion behavior of aluminum is reviewed for the non-specialist. Included is a discussion of the following topics: the relative nature of corrosion resistance, resistance criteria, factors influencing corrosion rates, common corrosion problems, how to choose an alloy; and galvanic, deposition, crevice and pitting corrosion. Specific information is given on corrosion in six major environments. Other topics considered include corrosion of brazed and welded joints, atmospheric performance of anodized aluminum and preventive measures.

Twenty-nine references are appended for persons interested in further study.

Introduction

THERE IS much information available on different aspects of the corrosion resistance of aluminum alloys which is well known to aluminum technologists. However there is not as yet any textbook on the subject, and the few review articles[1,2,3,4,5,6,7,8] published thus far differ somewhat from the present approach. This paper reviews the practical corrosion behavior of aluminum. It is written for the non-specialist who requires a general summary rather than specific facts; literature references are included for those interested in further study.

Before considering the corrosion resistance of any metal it is well to review the factors that influence its behavior.

Relative Nature of Corrosion Resistance

"Corrosion resistance" depends on the environment as well as on the metal and thus is not a fundamental property as is specific gravity, tensile strength, or electrical conductivity. This variation with environment differs from one metal to another and hence the relative performance of two metals will vary with the conditions of service.

As an example the author's company recently exposed foot square plates of quarter-inch mild steel and aluminum alloy (Alcan 65ST: US 6061-T6) on a rack facing the open Pacific Ocean near Port Alberni, B. C., about half way up Vancouver Island. Two years later, and after removal of corrosion products, the steel plate had lost 940 grams (about 20 percent of its thickness) while the aluminum plate had lost only 1 gram. Allowing for the difference in density the penetration ratio was about 300 to 1. On the other hand if tanks of steel and aluminum were used to contain caustic soda the corrosion ratio would be even greater—but in favor of steel!

Such differences in relative behavior also are true within one family of alloys. Some time ago seven aluminum alloys were tested in a series of acids (sulfuric, hydrochloric, nitric) and in a series of alkalis (caustic, soda ash, trisodium phosphate).

Alcan 75S (US 7075) showed the poorest performance of seven alloys in the acid media, but the best of the seven in the alkaline solutions, while Alcan 2S (US 1100) showed second best in acids, but seventh in alkalis. Super-purity (>99.99 percent Al) performed well in both types of solution.

Hence, in considering a corrosion problem, it is important to be specific as to the conditions of use. Even within one environment the severity of corrosion conditions will affect the relative rating of two alloys (though not their relative position). For example, Alcan 17ST (US 2117—an Al-Cu alloy) may corrode 10 times as fast as Alcan 57S (US 5052—an Al-Mg alloy) on board ship, but a few miles inland it may corrode only 1½ times as fast.

Corrosion Resistance Criteria

There is no uniform criterion or "yardstick" to measure corrosion resistance, because the seriousness of a given amount of corrosion depends on the use to which a metal is put. A corrosion rate that can be tolerated in one application may be completely unacceptable for another. The most common criteria for the evaluation of corrosion resistance are:

1. Perforation
2. Loss of strength
3. Impairment of appearance
4. Contamination of a product

★ Submitted for publication December 20, 1954. Based on a talk given at the First Annual Meeting of the Canadian Region of NACE, Toronto, Ontario, February 12, 1954.

In applications such as hot water tanks, water pipes, roofs, or flashings, resistance to perforation is most important. On the other hand a load-bearing pile can perforate without material loss of strength, and in this case resistance to mechanical failure is most important. In metal window frames and storefronts, resistance to impairment of appearance is the important property. In the chemical and food industries resistance to contamination of the product by metal pickup from process equipment is often the most important corrosion criterion, and a corrosion rate negligible from the point of view of equipment life may be quite unacceptable.

Thus, for a given use it is important to choose the right criterion for evaluating corrosion. If this is made too restrictive, a metal that is really quite suitable may be excluded. The layman accepts the fact that steel rusts, and rarely gives the matter a second thought. On the other hand he is apt to view with concern the greying that accompanies the weathering of aluminum, even though it is of no practical significance with regard to durability.

Importance of Corrosion Rate Curves

The rate of corrosion of a metal is rarely constant, and thus it is important to know the shape of the corrosion rate curve for any given use. This may take one of the three general forms shown in Figure 1.

The steady rate applies in most cases of general dissolution, such as zinc in battery acid or aluminum in caustic, but does not hold for most practical cases of corrosion. The decreasing rate curve is the most common and is typical for metals exposed to the atmosphere. The shape may vary from the linear type shown in Figure 1 to a steep initial rate tapering off with time.

Increasing rate curves rarely are encountered, especially with aluminum. All three types may be preceded by an induction or delay period during which there is no corrosion. If the curve is of the decreasing type it is obvious that a high initial rate often can be tolerated providing that the long term rate is low.

Factors Influencing Corrosion Rate

1. *Water*

By far the greatest amount of corrosion of metals is caused by the presence of water (its exclusion prevents corrosion). In general, the water must contain oxygen or air; if this is removed, corrosion ceases. Special cases of corrosion not involving water are high temperature oxidation, gas-metal reactions and the corrosion of metals by certain organic chemicals.

In some cases water may be beneficial. Aluminum exposed to an aggressive atmosphere corrodes more slowly if rained on frequently. For the reason that the water dilutes and washes away corrosive residues of soot or salt.

2. *Temperature*

Temperature has a strong accelerating effect on corrosion. In some cases, however, heat can prove beneficial by speeding up the rate of drying and thus reducing the period of wetness.

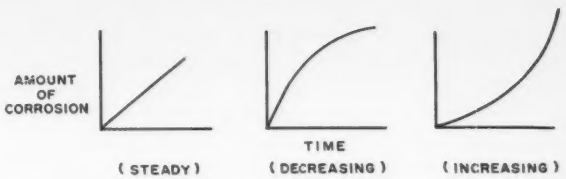

Figure 1—Typical corrosion rate curves.

3. *Movement*

Movement of the corrosive liquid usually accelerates the rate of corrosion. However, in the case of aluminum pitting in an aggressive water, movement will slow down the amount and rate of pitting and may even prevent it entirely. This fact can be utilized sometimes in design and provision made to avoid stagnant pools of water. At very high velocities (above 20 fps) which may cause turbulence at bends or fittings, localized corrosion of aluminum may develop. The presence of solids in a moving liquid may accelerate corrosion by eroding away an otherwise protective film.

4. *Surface to Volume Ratio*

The surface to volume ratio of a metal object will have a marked influence on its corrosion life. If the ratio is high it will corrode more rapidly than if the ratio is low.

For example the rate of deterioration of fine wires increases as the diameter of the wire is reduced; this is because the loss of a given thickness of metal is a larger percentage of the original for thin wires than for thick wires. A 1-inch diameter aluminum lightning rod on an industrial smoke stack lost 12 percent of its cross section due to corrosion in 28 years, yet remained an effective air terminal. On the other hand the stranded aluminum grounding cable (wires 0.140 inch diameter) corroded away completely at the mouth of the stack. An aluminum insect screen (wire diameter 0.012-inch) on a seashore cottage may deteriorate under conditions that will not measurably affect an aluminum roof on the same cottage.

5. *Heat Capacity of the Surface*

The heat capacity of a metal surface can affect the corrosion rate. This may be due to the thickness of metal itself or to the heat capacity of other objects to which the metal is affixed.

If an unpainted aluminum-skinned aircraft is poorly maintained, pitting may develop and will be most pronounced on the under side of the wings. This is due to the mass of the wing structure which, with its gasoline tanks, causes the under surface to have a slow rate of heating and cooling. Thus under conditions of change of atmospheric temperature such as occurs in the morning the surface remains colder longer than the rest of the aircraft skin and retains condensation for a long period. This effect has been demonstrated by exposing two panels of aluminum sheet in a horizontal position in the atmosphere, one with a large block of aluminum on top, and one ex-

posed by itself. After about a year, pitting was more severe on the under surface of the sheet beneath the block than on the single sheet even though the surfaces were side by side.

It has been demonstrated also that thick metal specimens corrode in the atmosphere at a slightly higher rate than thin ones.

6. Traces of Impurities in Liquid

In the chemical industry a considerable amount of information pertaining to corrosion experience with the use of metals has been accumulated. Much of this information has been tabulated with the inclusion of corrosion rates (either qualitative or quantitative) at various concentrations and temperatures. While the findings often prove helpful, the rates should be used with caution since in any specific case factors may be present which were not operative in the case for which the tabulated rates were compiled. The influence of velocity and entrained solids already has been mentioned.

More serious, and especially with aluminum, is the possible presence in the environment of traces of impurities which may not alter its quality appreciably, but which may greatly alter its rate of corrosion on aluminum. For example, traces of mercury even in the amount of a fraction of a part per million, may convert a non-corrosive chemical to a corrosive one.[9] Traces of copper in the liquid also are injurious to aluminum under some conditions.

In some chemicals, traces of moisture may make the chemical aggressive as in liquid sulfur dioxide, while in others (e.g., phenol) traces of moisture may inhibit corrosion that otherwise would occur. With aluminum the effect of most such deleterious impurities in chemicals is to induce pitting rather than general corrosion.

Corrosion Behavior of Aluminum

In general, aluminum is said to possess good resistance to corrosion. By this is meant good resistance to the atmosphere, to seawater, and to many fresh waters, chemicals, and foods.

This good corrosion behavior of aluminum is surprising in view of its high free energy content which usually means a strong tendency to corrode. Actually aluminum does corrode extremely rapidly until a surface film forms which arrests further action. This surface oxide film is extremely thin—about 50 Angstrom units. When the film is damaged or removed under conditions where reformation or repair is not possible, corrosion results. Thus the corrosion resistance of aluminum depends on the resistance of the oxide film to attack, rather than on the metal itself.

The oxide film on aluminum generally is stable in the pH range 5-8. There is a specific ion effect, however, since it is resistant to concentrated nitric acid at pH 1, to glacial acetic acid at pH 3 and to ammonium hydroxide at pH 13.

Aluminum is being used more and more widely in industry as its properties become better known. In Canada it is used extensively in the production of acetic acid, acetic anhydride, ammonium nitrate, chlorates, formaldehyde and glycerol. It is being introduced into the petroleum industry for heat exchangers, instrument tubing and sour crude oil storage facilities.

In the pulp and paper industry aluminum is used for logging flumes, heat exchangers and paper machine hoods. It is widely used in air-conditioning duct systems and for industrial roofing and siding. Increasing amounts of aluminum are being used in railroad passenger cars and on a small scale it is being used in railroad freight cars. It has proven satisfactory for refrigerator-car brine-tanks.

In the chemical industry, aluminum may perform well, fairly well, or poorly depending on the chemical. Where its corrosion properties permit, aluminum offers economy, light weight and good heat conductivity. Aluminum railroad tank cars are used to transport the chemicals listed in Table 1.

Common Corrosion Problems With Aluminum

In applications where aluminum has been found to be generally satisfactory, the most common corrosion troubles have been due to:

1. Improper choice of alloy
2. Galvanic corrosion
3. Deposition corrosion
4. Crevice corrosion
5. Pitting

Choice of Alloy

1 Wrought Alloys

Super-purity aluminum (>99.99 percent Al) and certain very high purity aluminum alloys containing magnesium and manganese exhibit the best corrosion resistance by a wide margin. This grade requires a special refining process. The introduction of impurities, particularly copper and iron, lowers the corrosion resistance appreciably; metal containing only 0.10 percent combined impurities already is inferior to Super-purity. Aluminum of 99.7 to 99.8 percent purity, which can be "high-graded" from normal production, performs somewhat better than commercial-purity metal and is used for special purposes such as cladding the interior of aluminum beer barrels. Commercial alloys usually are based on metal of 99.3 to 99.6 percent purity. Within this range there is little difference in behavior.

Alcan 3S (US 3003—1.25 percent Mn) has good corrosion resistance and is superior in some applications to 2S (US 1100—99.3 percent Al). In general the aluminum-magnesium alloys have the best corrosion resistance of alloyed aluminum. Examples are given in Table 2.

Alloys containing magnesium and silicon such as

TABLE 1—Chemicals Transported in Aluminum Tank Cars

Acetic Acid	Hydrogen Peroxide
Ammonium Nitrate	Milk
Butyl Aldehyde	Naphthenic Acid
Nitric Acid	Nylon Salt
Formaldehyde	Trichlorbenzene
Glycerol	Turpentine

Alcan 50S (US 6063) and Alcan 65S (US 6061) have good corrosion resistance though they are somewhat inferior in aggressive environments to the binary Al-Mg alloys first mentioned.

Alloys containing copper (Alcan 17S, 24S, 26S—US 2017, 2024, 2014, respectively) are stronger, but have less corrosion resistance and are not used in aggressive environments unless coated (or "clad") with a layer of pure aluminum.

Alloys containing Zn, Mg and Cu such as Alcan 75S (US 7075) are similar in corrosion behavior to the Al-Cu group.

2. *Cast Alloys*

In general the Al-Mg alloys have the best corrosion resistance and consist of:

Alcan	US
320	214
350	220

The Al-Si alloys have less, though still good corrosion resistance and are widely used. They include:

Alcan	US
123	43
135	356
160	—

The Al-Cu alloys exhibit generally poorer corrosion behavior and are not used under corrosive conditions. They include:

Alcan	US
225	195
236	B-113

3. *General Alloy Problems*

a. Clad Battle Scrap Roofing. Following World War II a number of aluminum producers in various parts of the world put out a cheap general purpose roofing sheet, usually corrugated, made from aircraft scrap metal. This had variable composition but commonly contained several percent copper and was clad with pure aluminum to give protection. However, because of diffusion of copper into the cladding, and lack of heat treatment, it failed to stand up under severe marine and industrial conditions and early perforation was frequent. After failure it could be recognized by an exfoliation type of corrosion at the holes and edges. Unfortunately stocks of this turned up in several parts of the world to give aluminum a bad name in some quarters.

b. Misuse of Al-Cu Alloys. From time to time Al-Cu alloys have been used for marine purposes, usually in ignorance of results, but sometimes through faulty alloy identification in the shipyard. For example a recent examination of a corroded aluminum life boat plate showed it to be Al-4 percent Cu alloy. Sometimes Al-Cu casting alloys (which have good castability and are suitable for many purposes) find their way into marine service and perform poorly. or example, a corroded port-light casting from a naval vessel recently was found to contain 7 percent copper.

Occasionally a properly heat-treated Al-Cu alloy section is heated with a blow torch (contrary to specification) to soften it for bending. This makes it easy to bend but renders it very much more susceptible to corrosion. A corroded section from the underframe of an auto bus which had received this treatment has been examined in this laboratory.

Hot-driven steel rivets through Al-Cu plate develop blistering of the aluminum under corrosive conditions. This creates a condition difficult to correct in view of the penetrating nature of the corrosion. The blistering is due in part to grain boundary precipitation in the alloy caused by the heat from the hot rivet, and in part to galvanic corrosion which intensifies the intergranular corrosion.

TABLE 2—Aluminum-Magnesium Alloys

ALLOY		
Alcan	US	Mg Content (%)
57S	5052	2.5
B54S	5154	3.5—4.3
56S	5056	5.0

Galvanic Corrosion of Aluminum

It is well known that aluminum stands high in most galvanic series and hence provision must be made to avoid galvanic corrosion when using aluminum in contact with other metals. This is one of the most common practical corrosion problems with aluminum and one that can be eliminated if attention is given to joint design and care of construction.

The further apart two metals are in a galvanic series, the greater will be the tendency toward galvanic action. However the *amount* or severity of galvanic corrosion cannot be predicted from the table alone, but depends on the following factors:

1. Electrical resistance of the joint
2. Conductivity of the solution
3. Relative anode and cathode areas
4. Polarization

Galvanic corrosion is mild in most fresh waters, strong in seawater and strong in conductive chemical solutions. In the atmosphere it is negligible in rural locations, mild in most city atmospheres, and strong in marine atmospheres. It is extremely severe on exterior locations on board ship and very bad on piers in the ocean, but decreases rapidly with distance from shore. A mile from the sea, galvanic corrosion is mild, and five miles inland can be considered to be rural.

The galvanic corrosion behavior of aluminum with other common metals is discussed below:

Zinc

In the atmosphere and in most waters, zinc is anodic to aluminum and will protect it when in contact with it. Thus aluminum may be placed safely in contact with zinc and galvanized steel in most uses. In a corrosive location, deterioration of the zinc coating may be accelerated and when this is gone

Figure 2—Aluminum-steel rivets and plate.

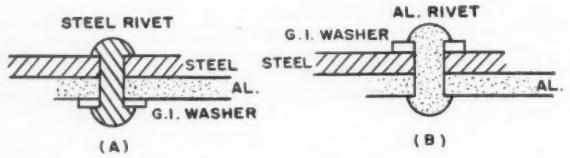

Figure 3—Galvanized washer as used with steel and aluminum rivets.

the exposed steel will cause corrosion of the aluminum. In such cases the assembly should be painted.

Cadmium

Cadmium is slightly cathodic to the Al-Mn, Al-Mg and Al-Mg-Si alloys and slightly anodic to the Al-Cu alloys and can be used safely in contact with them under all conditions. With cadmium plated steel or other metals it is imperative that a sufficient thickness of cadmium be used to avoid premature failure and development of an unfavorable couple with the metal beneath. Again, for corrosive locations, painting is recommended.

Chromium

In most fresh waters, and in all atmospheres, aluminum can be used in contact with chromium plate. Deterioration of the chromium may expose nickel which has less favorable galvanic relations with aluminum.

Stainless Steel

In normal atmospheres, and in fresh waters, aluminum can be used safely in contact with stainless steel. In *severe* marine atmospheres stainless steels tend to corrode aluminum; because of this such joints should be protected. In seawater also galvanic corrosion will occur, especially where the area relationships are unfavorable.

The combination of stainless steel and aluminum serves to illustrate the influence of polarization on galvanic corrosion. A comparison of the open circuit potentials between aluminum-stainless steel and aluminum-copper in seawater shows about the same value, yet in the latter cases galvanic action is much stronger. The former couple polarizes appreciably to produce much smaller galvanic corrosion currents.

Steel, Iron

In all but marine environments the galvanic action of steel and iron on aluminum is slow. There is less action with aluminum alloys containing copper.

In marine atmospheres and in seawater, aluminum to steel joints should be electrically insulated where possible. Where direct contact must be made, as in the building of an aluminum superstructure on a steel ship, the steel portion of the contact should be galvanized or sprayed with aluminum. An inhibitive jointing compound should be used and a good overall paint system applied and maintained. Steel rivets are preferred and are a necessity if the joint is to be damp or underwater; where possible a galvanized washer should be placed under the rivet head on the aluminum side. Where this is not feasible the steel rivet head and the surrounding aluminum plate should be sprayed with aluminum and painted.

This couple can be used to illustrate the influence of cathode/anode ratio on the amount of galvanic corrosion.

In contact with seawater the amount of galvanic corrosion current that can flow is limited by the area of the cathode (steel). Note the two drawings in Figure 2. In case A with an aluminum rivet head in a steel plate the small rivet head will attempt to feed current to a large area of the plate, and soon will be consumed. In case B the small steel rivet head will accept only a small amount of current which is trying to flow from a large area of aluminum plate. Thus there will be less total corrosion and far less loss of aluminum in any one place.

The foregoing argument holds for immersed conditions. In the atmosphere, galvanic action is confined to a narrow band about ⅛-inch wide near the junction and thus equal areas of anode and cathode can be assumed so that cases A and B should be similar. However, it is preferable for the plate rather than the rivet to corrode since a corroded fastener leads to structural failures. The role of a galvanized washer can be seen in Figure 3.

Use of Galvanized Washer in Riveted Aluminum-Steel Joint

A galvanized washer should be placed on the aluminum side if a steel rivet is used and on the steel side if an aluminum rivet is used. This makes the dissimilar metal pair Al-Zn in each case rather than Al-Fe and such a junction is kept painted more readily.

Copper

Connections to copper and its alloys represent the most unfavorable galvanic couple that will be encountered with aluminum and its alloys, and should be avoided where possible.

However, in a dry atmosphere Al-Cu couples are satisfactory. Refrigerators sometimes employ copper and aluminum tubing with a flash butt welded joint that does not give trouble. In manufacturing plants, copper to aluminum bus bar joints seldom corrode. Even on the *Aquitania*, such connections showed negligible corrosion after 37 years transatlantic service. For corrosive locations tin plating of the copper is recommended.

Copper nails driven through aluminum sheet have

failed to produce appreciable corrosion of the sheet in a semi-rural atmosphere (Kingston, Ont.) after eight years, and only incipient pitting is evident. More serious corrosion would be expected, however, in a marine atmosphere.

Water systems containing mixed copper and aluminum piping are not recommended unless the direction of water flow is from aluminum to copper. This should be taken into consideration to avoid the possibility of deposition corrosion in the reverse case.

Nickel

In general nickel and nickel alloys, such as monel, in contact with aluminum approach stainless steel in their galvanic influence, except in seawater and in severe marine environments where their influence is closer to that of copper.

Lead

Aluminum may be used in contact with lead in all but marine temperatures. Lead washers commonly are used on galvanized nails to secure aluminum roofing sheet. In one case the marine-industrial atmosphere of Sydney Harbor, Australia, took 37 years to cause perforation of an 0.032-inch roofing sheet around a lead washer.

Titanium

Titanium may be used safely in contact with aluminum under most conditions except immersion in seawater (when it produces slightly less galvanic corrosion than stainless steel).

Magnesium

Magnesium is anodic to aluminum and corrodes preferentially when coupled. In corrosive atmospheres such contact also may corrode the aluminum as a result of the buildup of alkali by the local cell (cathodic corrosion). Certain aluminum alloys such as the following which contain magnesium, have superior galvanic relations with magnesium:

Alcan	US
57S	52S
54S	54S
56S	56S
320	214
350	220

Summary of Galvanic Effects

It has been found that aluminum can be coupled safely to zinc, cadmium, and chromium in all locations. Titanium and stainless steel are next best; then steel and then lead. Copper and its alloys should be avoided where possible although the severity of galvanic corrosion is influenced markedly by environment.

Deposition Corrosion

"Deposition corrosion" is a special case of galvanic corrosion, and results from the deposition of particles of a more noble metal on the surface of another metal. This may be caused by settling or be the result of electrochemical action. These particles set up local element cells and in the case of aluminum lead to pitting corrosion.

The most aggressive ion to aluminum is mercury, even traces of which may pose serious problems. Fortunately these ions are rarely present in commercial aqueous solutions, but occasionally they are found in unexpected places; e.g., a number of aluminum drums containing a non-aggressive chemical perforated from the outside during shipment overseas as deck cargo. The trouble was traced to a mercury-containing dust that had settled on the tops of the drums during storage before shipment. In another case a few tenths of a part per million of mercury in glacial acetic acid was found to cause pitting of aluminum upon dilution of the acid.

Traces of copper in waters and in solutions are a more commonly encountered cause of deposition corrosion of aluminum. Again even small concentrations (perhaps a few tenths of a part per million) are detrimental.

The following practices can be adopted to minimize the severity of deposition corrosion:

1. Redesign of equipment
2. Use of alclad aluminum
3. Use of inhibitors
4. Frequent cleaning

It may be possible to redesign a system in which deposition is found so as to avoid the deposition of the more noble metal. This may involve replacing other metal parts in the system or changing the direction of liquid flow. Use of alclad aluminum (72S clad on 3S) may lengthen the time to perforation to an acceptable value. Inhibitors, if feasible, may prevent corrosion. Frequent cleaning, if possible, will be beneficial.

In one experiment[10] water containing 0.5 ppm copper was heated in two aluminum saucepans. Every four hours the water was poured out and renewed. At each change one saucepan was cleaned with steel wool while the other was not cleaned. The uncleaned utensil perforated after 300 hours while the cleaned pan was still far from perforation after 1000 hours.

In a recent case brought to the author's attention, the bottom of an aluminum beer fermenting tank was pitted in a localized manner so as to show the "shadow" shape of a copper cooling coil above it. This was caused by the use of an aggressive cleaner on the coil which dripped copper ions to the tank bottom below; pitting resulted when these ions were not adequately removed by cleaning the tank bottom. Other similar installations, which have been properly cleaned, have shown no such pitting.

Crevice Corrosion

Crevice corrosion most commonly is encountered when water is trapped in the crevice between the faying surfaces of a joint. Pitting develops just inside the crevice where the metal is in contact with water depleted of oxygen. An anodic condition exits here

relative to the mouth of the crevice where the water is saturated with oxygen.

Crevice corrosion can be avoided by eliminating, where possible, crevices that will trap water; crevices that cannot be eliminated should be filled with an inhibitive jointing or sealing compound.

Aluminum window frames, door jambs, etc., are back painted not so much to prevent corrosion by contact with stone, bricks, concrete, etc., as to prevent crevice corrosion that could result from entrapped water.

An aluminum conduit fastened tightly along a concrete wall may corrode along the line of contact, not because of the corrosiveness of the concrete, but because of the water trapped in the crevice formed. Even distilled water between sheets of aluminum will produce crevice corrosion; aluminum pipes and tanks, however, commonly are used to contain distilled water and do not corrode.

Pitting Corrosion

Pitting corrosion of aluminum occurs under conditions where the oxide film is almost, but not quite, completely protective. It may occur also when the film is damaged mechanically, or as a result of deposition corrosion.

Aluminum pits in some natural waters, although water movement (in the order of 10 fpm) may prevent its initiation. Lesser speeds will reduce the rate of penetration.[11] Once pitting has started it may continue regardless of the cause of initiation. In other words, the mechanism of initiation and propagation are different. In waters of all types the rate of pitting falls off rapidly with time, roughly decreasing by a cube-root function. This means that doubling the wall thickness will give eight times the life in a given application.

Temperature tends to increase the rate of pitting of aluminum by water up to about 40 C after which the rate slows appreciably.

Super-purity aluminum has by far the greatest resistance to pitting and can be alloyed to some extent (e.g., Mg, Mn, Zn) without loss of this property. However, if a few pits do develop they may penetrate more rapidly than in lower purity commercial alloys. Maximum resistance to penetration by pitting is obtained with alclad alloys (e.g., 72S on 3S; US 7072 on 3003—for handling waters). Of the unclad alloys, Alcan 57S (US 5052) has the lowest pitting tendency and also the lowest pitting rate. Alcan alloy 65ST (US 6061-T6) has a somewhat higher pitting tendency, but in many cases the rate of penetration is slow and compares favorably with Alcan 57S (US 5052).

Pitting can be prevented by the use of inhibitors or by means of cathodic protection. In the latter case overprotection with cathode alkali buildup must be avoided.

Intergranular Corrosion

Intergranular corrosion (also called intercrystalline corrosion) is a form of localized sub-surface attack in which a preferential path of small dimensions is corroded out along the grain boundaries of the metal.

Certain aluminum alloys can, under favorable circumstances, suffer intergranular corrosion. The severity may vary from slight to appreciable depending on the alloy system and the environment. The number of corrosion complaints due to this cause is relatively small.

In its early stages intergranular corrosion may appear as blisters that can be pried open with a penknife to reveal a "soda cracker" appearance. Upon further attack the periphery of the corroded area develops an exfoliated appearance with fissures leading into the metal (usually parallel to the surface) which can be probed with the tip of a knife. An extreme case is that of lamellar corrosion when thin layers of metal are separated like the pages of a book.

In severe cases a marked loss of mechanical properties may occur even though only a small volume of metal may have been corroded. Where a structural member is subject to stress under conditions of intergranular corrosion, rapid failure of the member may occur as a result of stress corrosion.

Intergranular corrosion does not occur in practice with the common work hardening alloys and thus Alcan alloys 1S, 2S, 3S, 4S, 54S, 56S and 57S (US 52S) are not affected. An exception is 56S which may become susceptible under very unfavorable circumstances, such as long time service at elevated temperatures.

Intergranular corrosion may be encountered with certain heat treatable alloys if the composition, the thermal history and the severity of corrosive conditions are right. Susceptibility is least evident when the alloy has been properly heat treated. The solution heat treated form "W" is more resistant than the fully heat treated form "T" (solution heat treated and precipitation heat treated). In the case of the Al-Cu alloys Alcan 17S, 24S and 26S (US 14S) in the properly heat treated condition, intergranular corrosion will occur only under severe conditions such as exposure to seawater.

Cladding (with 1S) will prevent intergranular corrosion. While extrusions cannot be clad they can be sprayed with 1S which protects them against this type of corrosion. These alloys should not be heated by the fabricator because rapid heating and slow cooling leads to the precipitation of copper aluminide in the grain boundaries; this could result in the alloys being made very susceptible to intergranular corrosion.

With the Al-Mg-Si alloys, Alcan 50S (US 63S) and 65S (US 61S), intergranular corrosion occurs to only a minor degree even under the worst conditions. It usually is associated with pitting and is not serious from a structural point of view.

With the Al-Zn-Mg-Cu alloy, Alcan 75S, intergranular corrosion may occur under unfavorable conditions. Cladding (with 72S) prevents this.

Stress Corrosion

Stress corrosion failure (stress corrosion cracking) of aluminum alloys is encountered infrequently in service. High stresses—approaching the yield stress—usually are required. These may be applied or residual ("locked-in" stresses due to fabrication). Most of the cases observed have occurred in aircraft parts and

have been the result of high internal stresses. In all cases it has been possible to eliminate the problem by redesign of the part in question or by change of fabrication procedure.

Properly heat treated aircraft clad sheet alloys such as Alcan 24S, 26S (US 14S), 75S are not subject to stress corrosion. Machined extrusions or forgings which cannot be clad and in which design stresses have been high have provided most of the cases encountered.

The Al-Mg-Si alloys, Alcan 50S (US 63S) and 65S (US 61S), have not been found to stress corrode in service.

The orientation of the applied stress with respect to the direction of working may have considerable influence on susceptibility to stress corrosion. This is most marked in the short transverse direction (see Figure 4 and is particularly true in 75ST.

Stress corrosion is possible, though not common, in the Al-Mg series provided that the Mg content is in excess of 5 percent; this is especially true in elevated temperature service. The cast alloy Alcan 350-W (US 220) is subject to stress corrosion in a corrosive environment under high applied stresses.

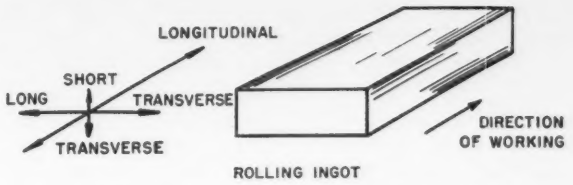

Figure 4—Applied stress in respect to direction of working on a rolling ingot.

Corrosion of Aluminum in Specific Environment

1. *Natural Waters*

Only limited information is available on the corrosion of aluminum in natural waters. A good statement is that of Sawyer and Brown.[12] More recent is the work of Porter and Hadden.[13]

If corrosion does occur it is in the form of pitting. It is not possible as yet to predict the behavior of aluminum with certainty from a table of water composition; a field trial must be made (which may be completed within a year). However, some general conclusions can be drawn from experience thus far. Very soft waters such as those at Arvida, Quebec and Ottawa, Ontario, do not corrode aluminum and its use for water piping in these locations is feasible. A recent inspection of aluminum piping in some government financed houses in Ottawa after six years showed them to be free of corrosion. Fairly hard waters such as that at Kingston, Ontario, and hard water such as that at London, Ontario tend to pit aluminum and its use for water piping in these locations would not be feasible. Traces of copper will cause pitting in either hard or soft waters. High solids soft alkaline waters are corrosive to aluminum.

The beneficial effects of velocity, cladding and cathodic protection already have been mentioned.

One use of aluminum for handling waters that has been very successful is in portable-pipe irrigation systems. Despite the very thin wall (e.g., 0.050-inch), few pitting troubles have been reported. This is attributed to two facts 1) when full, the water is moving, and 2) during moving of the system, the interior wall dries.

Another use of aluminum that promises to be very successful is for domestic hot water tanks. In very aggressive waters corrosion may be encountered, but these locations also are corrosive to other metals. In this case the reduction in pitting rate with temperature is probably a factor.

2. *Seawater*

Aluminum alloys are quite resistant to seawater. A corrosion rate of about 0.4 mpy or one-tenth the rate for steel was found for Alcan 57S (US 5052) at Harbor Island, N. C. Alloys containing appreciable amounts of copper (e.g., Alcan 17S, 24S, 26S—US 2017, 2024, 2014) corrode more rapidly and should not be used. In the splash and spray zone the superiority of aluminum over steel is even more marked. The 300 to 1 corrosion ratio of steel to aluminum on the northwest Pacific Coast already has been mentioned.

Two good papers on the marine performance of aluminum are those of Mears and Brown[14] and Walton and Englehart.[15]

3. *Atmosphere*

In rural atmospheres the corrosion of aluminum is barely detectable (less than 0.001 mpy). In city and marine atmospheres it tends to corrode more rapidly; the rate stays between 1-4 mpy for the first six months to two years (depending on locality and alloy) and then slows markedly to rates in the order of 0.1 mpy. The rate of corrosion on a 52 year old aluminum cornice on a downtown Montreal building in a heavy industrial atmosphere was 0.12 mpy. The longest actual exposure test values reported are:[16]

	mpy
Georgetown, B. G.	0.03
New Kensington, Pa.	0.08
Point Judith, R. I.	0.11

Information on the performance of aluminum alloys in chemically polluted atmospheres has been given by Binger et al.[17]

A recent paper[18] which made use of available corrosion rates and 1953 metal costs in Montreal gave figures on the annual cost of corrosion of several common metals using the unit $/1000 square feet/year (see Table 3).

It can be seen that in rural atmospheres, aluminum is by far the cheapest architectural metal. In marine atmospheres, lead has the lowest annual corrosion cost followed by aluminum and copper. In industrial atmospheres lead again is best followed by aluminum, then copper. Unfortunately lead must be applied fairly thick (3 lbs./square foot = 0.050-inch; 5 lbs./

square foot = 0.083-inch) and the first cost of a large installation is excessive.

4. *Soil*

Little has been published on the soil corrosion behavior of aluminum alloys, but large scale test programs are now underway which should provide considerably more information in the next few years. In general, it is agreed that the corrosiveness of soils to aluminum varies greatly from one type to another and that the moisture content is an important factor, poorly drained wet soils being generally more corrosive. If corrosion does occur it usually takes the form of pitting or etched patches with small weight loss, so that the rate of penetration is the most important criterion.

In the US Bureau of Standards soil corrosion program,[19] specimens of 2S, 3S and Al-4.1 percent Cu alloy were buried in five soils which are listed in decreasing order of corrosivity:

	pH
muck	4.2
sandy loam	9.5
Susquehanna clay	4.7
alkaline soil	7.4
tidal marsh	3.1

After ten years the Al-Cu alloy had completely disintegrated in the first two soils and had perforated in the other three. The other two alloys had pitted severely in all but the tidal marsh, where corrosion was slight (maximum penetration 13 mils).

In an English test program[20] commercially pure aluminum sheet and tubing were buried for five years in five soils which are listed in order of corrosivity:

1. Cinders
2. Salt marsh
3. Keuper marl
4. London clay
5. Moist neutral clay

These soils were all slightly alkaline in the pH range 7-8 and produced severe pitting except for the neutral clay in which aluminum was virtually unaffected.

Several short buried aluminum pipe lines carrying oil and gas are now in service in the United States with uncoated test sections. One test shows that a Louisiana salt marsh is relatively non-corrosive to aluminum.[21]

In a small test program the author has found Al-Mg alloys such as 57S (US 52S) to be the most resistant to soil corrosion in several locations.

5. *Underground in Mines*

Aluminum equipment has been used in mining extensively and with satisfaction for such purposes as skips, cages, hopper cars, pit props, and tools. Performance varies with the nature of the ore body and in particular with the composition of the mine water. Aluminum has been used widely in the gold mines of Northern Ontario since 1931[22] and in South Africa. It has been used extensively in English, German and Canadian coal mines as well as Canadian asbestos mines.

6. *Building Materials*

Aluminum frequently is employed in contact with building materials. It is used, for example, in the form of electrical conduit embedded in concrete, as flashings or window frames in contact with stone and brick, and for air conditioning ductwork.

Concrete corrodes aluminum at a slow rate during the setting period, after which the rate is negligible even when wet, although moisture does increase it slightly. Mixes rich in cement (e.g., grout) are more corrosive. The presence of calcium chloride in the concrete (used to promote rapid setting during winter pouring in cold climates) is not deleterious to aluminum although in such cases the aluminum must not be in contact with embedded steel or galvanic corrosion may occur.[23] Temporary protective coatings frequently are applied to aluminum window frames etc. to protect the surface from spotting caused by concrete and mortar spillage during construction.

Portland cement mortars and stuccos are not appreciably corrosive to aluminum; neither are hardwall plasters.

Corrosion of Welded, Brazed and Soldered Joints

In general, welded and brazed aluminum joints are as corrosive resistant as the parent metal, although there are some exceptions. For example, welds deteriorate in the presence of moderately strong nitric acid. Welds in Al-Cu and Al-Zn-Mg-Cu alloys are less resistant. In the chemical industry it is well to consider the possible corrosion of welds at the design stage, and to make tests if their performance is not known. In waters and in the atmosphere, no localized corrosion at welds should be encountered. Fluxes, if used, must of course be removed.

The corrosion behavior of soldered aluminum joints has been described by Dowd.[24] Non corrosive organic fluxes can be used with soft solders, but the corrosion resistance of the joints is limited and protection is recommended. Corrosive chloride fluxes are required for hard solders and must be removed after soldering.

The best solders from the corrosion standpoint are zinc base alloys in which zinc is the lowest melting

TABLE 3—Relative Cost of Atmospheric Corrosion of Metal Roofing

Metal	Thickness	$/Sq. Ft.*	Corrosion Rate (m.p.y.)**			Cost of Corrosion in $/1000 Sq. Ft./Year		
			Rural	Marine	Indust'l	Rural	Marine	Indust'l
Aluminum	0.032	0.150	0.001	0.11	0.08	0.005	0.52	0.37
Copper	0.032	0.975	0.023	0.023	0.045	0.70	0.70	1.37
Lead	0.085	1.000	0.019	0.020	0.022	0.22	0.24	0.26
Steel	0.018	0.073	1.5	2.0	5.0	6.1	8.1	20.2
Galvanized Steel (1.5 oz./sq. ft.)	0.022	0.127	***	***	***	2.9	5.7	11.9

* In 1,000 pound lots, Montreal, Que., 1953.
** From 10-year ASTM results except for Al., steel.
*** These rates are mixed, depending first on zinc and then on steel.

metal. However, even their corrosive resistance is limited in aggressive environments and protection is necessary.

Atmospheric Performance of Anodized Aluminum

Indoor anodized architectural sections require no attention to preserve their appearance other than periodic cleaning to remove dust which will show against the light background of the metal.

Outdoor anodized aluminum should be cleaned periodically in urban locations because soot residues will in time lead to pitting. Water, detergent and a mild abrasive such as pumice may be used. Waxing is beneficial and probably will last about three months per application.

A convenient alternative treatment involves the use of a 10 percent solution of Rohm and Haas resin Acryloid B-72 in xylol. This is applied with a cloth once every three months. A resin solution-wetted cloth will remove the grime and last resin film while a second clean cloth can be used to wipe on a fresh film. A thicker brush or spray-applied clear lacquer cannot be expected to last for more than about two years.

If maintenance is not carried out the surface appearance will deteriorate, but corrosion will not be serious from a structural point of view.

Prevention of Corrosion of Aluminum

1. *General*

Because of the fact that most corrosion is electrochemical, most corrosion preventive practices are based on: 1) interruption of the electrolytic circuit, 2) establishment of a controlled directed circuit (cathodic protection), or 3) reduction of the current in the circuit by increasing the resistance or the polarization.

Preventive measures fall into several classes:

1. Coatings
   a. Metallic
   b. Inorganic
   c. Organic (paints, plastics)
2. Alteration of the environment
   a. pH control
   b. Aeration or deaeration
   c. Changes in temperature, velocity
   d. Inhibitors
   e. Cathodic protection
   f. Design

Examples of metallic coatings are electroplate, metal spraying (metallizing) and cladding. Inorganic coatings are of the vitreous enamel type, and have been developed for aluminum. Paints will be dealt with briefly as a separate section.

The influence of pH, oxygen, temperature and velocity already have been mentioned.

Inhibitors often can be used in closed systems, as for example in brine cooling systems. A review of inhibitors for aluminum has been given by Mears and Eldredge.[25]

Aluminum can be cathodically protected in fresh and salt waters, but in soils where alkali buildup is more rapid this method has not been used and its suitability is doubtful. The cathodic protection of aluminum in chemical equipment has been described by Mears and Fahrney.[26]

2. *Paint*

A full treatment of this subject of paint is beyond the scope of this paper. It may be said briefly that suitable techniques and paints exist, and that painting of aluminum is simple and satisfactory. It is essential that the surface be clean and a suitable primer should be used. Proprietary agents of a phosphoric acid type exist which aid paint adherence. On the other hand, the recently developed wash primer provides an excellent base for a subsequent paint system and requires only prior cleaning as a pretreatment. A general review of the subject has been published.[27]

Aluminum usually is painted for aesthetic reasons rather than for corrosion prevention. In general a paint system on aluminum will outlast a similar system on steel since, when moisture permeates the paint film, it has less action on aluminum. Porcelain enameled aluminum has evoked much recent interest and is described by Bricker.[28]

3. *Influence of Design*

The subject of the influence of design on corrosion has been dealt with by Mears and Brown.[29] Inasmuch as the corrosion behavior of a metal is influenced by the physical conditions of the environment (temperature, movement, differential concentrations, etc.) as well as by its chemical composition, the design of the metal equipment can affect the nature and the rate of corrosion. Corrosion sometimes can be reduced or eliminated by enlarging a heating surface to enable its temperature to be lowered; by changing the shape of a pipe inlet to avoid impingement; or by avoiding corners difficult to clean and by eliminating crevices, etc. Mention already has been made of a number of specific cases in which design affects the nature and amount of corrosion.

Conclusion

The general corrosion behavior of aluminum alloys and the influence of environmental factors on performance have been discussed at some length. Aluminum has been shown to have good corrosion resistance in many applications, to be the preferred metal for some and to be unsuitable for others. In common with all architectural and structural metals it performs best when attention is paid to design, alloys, and methods of installation.

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Any discussions of this article not published above will appear in the June, 1956 issue.

Discussions

Electrical Measurements Applied to Corrosion Investigations by William R. Schneider and David Hendrickson. *Corrosion*, Vol. 10, No. 10, 337-342, (1954) Oct.

Remark by O. W. Wade:

The use of the surface potential method as a method for locating coating holidays has proven to be successful. This method of locating coating holidays is accomplished by energizing the structure with an interrupted DC current and observing the relative change in potential produced. The frequency of interruption should be of the order of two to four second periods. In areas where considerable AC ground currents are prevalent, the use of the surface potential method for the location of holidays has been found to have advantages over the method which uses an AC source of energy.

Proposed Standardized Laboratory Procedure for Screening Corrosion Inhibitors for Use in Oil and Gas Wells. Publication 55-2. *Corrosion*, Vol. 11, No. 3, 143t-146t (1955) Mar.

Question by John K. Shaw, Charles Pfizer and Co., Brooklyn, New York:

The object of a corrosion inhibitor test is to decide whether or not the inhibitor would be of value in a particular system. Has a corrosion rate been determined which would serve as a basis for deciding the positive or negative value (worth) of the inhibitor under test?

Reply by J. C. Spalding, Jr.:

The object of this corrosion inhibitor test is to screen compounds as to their possible application to this particular system. A corrosion rate obtained in this system has not been found that would serve as a basis for deciding definitely whether or not a corrosion inhibitor would be of value in this system. However, those inhibitors exhibiting less than 80 to 90 percent protection in the 25 to 100 ppm range probably would not be considered (barring economics) for further testing. This is only a preliminary indication and may be modified considerably by later findings.

Question by Frank E. Davie, Los Angeles, Cal.:

How well do different laboratories agree on weight loss of control coupons? Can this weight loss be taken as a constant?

Reply by J. C. Spalding, Jr.:

Different laboratories do not agree very well on weight loss of control coupons and this weight loss cannot be taken as a constant. For this reason the test specifically states that duplicate controls be run at the same time each inhibitor is screened. It may be stated that the weight loss of control coupons between laboratories agrees as well as it does within any given laboratory.

Question by Harry Kroll, Geigy Chemical Corp., Providence, Rhode Island:

How did you arrive at the 10 second immersion time of the steel coupon? What is the effect of variation in immersion time on the results of the test?

Reply by J. C. Spalding, Jr.:

The 10 second immersion time of the steel coupon was arrived at on the basis of tests performed by one of the member laboratories in a similar test experimented with over a period of several years. The effect of variation in immersion time has not been reported on absolutely. But this factor has been stated by certain parties to affect individual answers or numbers while having little effect on the overall results of rating the inhibitors.

Remark by Emile Pragoff, Jr., Hercules Powder Co., Wilmington, Delaware:

I would like to congratulate the committee on its work on what we feel is really an "aptitude" test. This test can and should be used to predict that a certain material has "aptitude" as an inhibitor for certain sour well conditions and therefore may be worthy of further evaluation.

Our company has been glad to take part in the program of studying the reproducibility of this test. However, we on the side of the manufacturers would like to see a different attitude on the part of the committee toward inhibitor manufacturers. We feel that we well may have a joint responsibility. The producing companies have certain needs and we want to fill them. Any tool or test which will help qualify materials which industry can use and can make should result in better inhibitors. But we will not achieve progress just by being critical of inhibitor manufacturers. Let's work together to put such a test to its indicated use as an "aptitude" test; manufacturers then will offer materials more useful to producers.

Reply by J. C. Spalding, Jr.:

The Committee thanks you for your congratulations. We agree that this test can be used only to predict future utility and is not an all-inclusive test. We are appreciative of the attitude adopted to this test by the inhibitor manufacturers and of the realization on the part of the manufacturers that acceptance of any material without a screened evaluation should not be expected. We agree that the use of

this test and future ones developed for other situations will lead to the presentation by manufacturers of better materials.

Laboratory Development of Corrosion Inhibitors by Loyd W. Jones and Jack P. Barrett. *Corrosion*, Vol. 11, No. 5, 217t-220t (1955) May.

Questions by R. S. Treseder, Shell Development Co., Emeryville, Cal.:

1. Do you have any information on the high temperature stability of the inhibitor concentrate?
2. Is the inhibitor effective in hydrogen sulfide-air systems where corrosion scale is in contact with the steel surface, e.g., at places of low velocity?

Replies by Loyd W. Jones:

1. A complete investigation of the effects of high temperature has not been made. We have found that prolonged heating of the concentrate to 300 F and higher can cause the inhibitor to start losing effectiveness. In dilute oil solution, however, the inhibitor has proved to be quite effective in preventing corrosion of refinery vessels at temperatures above 400 F.
2. The inhibitor possesses excellent surface activity and detergency. Consequently, corrosion scales are penetrated and dislodged from the metal surfaces. The wetting action has been observed many times in the field by increased amounts of iron sulfide and oxide in the effluent of water lines, heater treaters and the like, when inhibitor treatment is started. Laboratory tests have shown the inhibitor will penetrate water wet corrosion scales.

High Temperature Corrosion Data. Publication 55-6. *Corrosion*, Vol. 11, No. 5, 241t-245t (1955) May.

Comments by Anton deS. Brasunas, American Society for Metals, Cleveland, Ohio:

The summation of high temperature corrosion data which appeared in the May 1955 issue of *Corrosion* undoubtedly will be extremely convenient to many users of various high temperature alloys for corrosion resistant applications. Because air is frequently in contact with heat resistant alloys, especially iron-nickel-chromium alloys, the writer believes that a nomograph relating the nickel and chromium contents with the extent air-corrosion at a wide range of temperatures,[1] would be a valuable addition to this compilation.

This chart summarizes the results of approximately a thousand corrosion tests performed for the Alloy Casting Institute at Battelle,[2] and constitutes a concise presentation of a wealth of air-corrosion information.

It should be emphasized that these data were obtained in 100-hour tests in moist air (~4 percent H_2O)

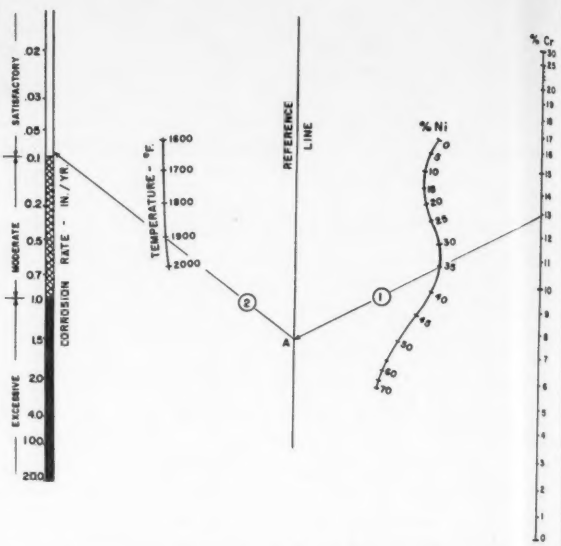


Figure 1—Air corrosion of iron-nickel-chromium alloys which also contain about 0.4 percent C, 1.2 percent Si, and 0.8 percent Mn.

on cast samples which also contained approximately 0.4 percent carbon, 0.8 percent manganese, and 1.25 percent silicon. Variations in alloy composition will have some effect on corrosion behavior. This will be particularly true with the presence of corrosion-accelerating substances, such as sulfur, vanadium, lead, etc., in the environment.

The following information should appear on the proposed data sheet:

> One may determine the approximate extent of corrosion by air to be expected of any iron-nickel-chromium alloy within the range 0 percent to 70 percent nickel and 0 percent to 30 percent chromium at temperatures between 1600 and 2000 F. Although one may extrapolate to temperatures above and below this range by the use of this nomograph, this graph is based on experiments within this range.

The nomograph pictured in Figure 1 is based on 100-hour test data of Brasunas, Gow, and Harder (*Proc. ASTM* **46**, 1946, 870) and presents a very convenient condensation of a large volume of high temperature corrosion data. Loss in accuracy is to be expected in condensation and the reader is referred to the original reference for more accurate corrosion data.

The nomograph can be used in the following cases as described below:

1. *When alloy composition and temperature are known.*

If an alloy of 13 percent chromium and 35 percent nickel were contemplated for use in air at 1900 F, it would be possible to estimate the corrosion rate as follows: Draw a straight line connecting the percent nickel and chromium (line 1) and note its intersection at the reference line (point A); then draw another line from this intersection through the temperature selected and read the corrosion rate—in this

(1) *Metal Progress*, **66**, 6, p 114B, 1954 (Dec.)
(2) *Proc. ASTM*, **46**, 1946, p 870.

case about 0.09 inch/year. (This is for a 100-hour test of continuous exposure.)

2. When the temperature and amount of corrosion tolerable are known.

A composition could be selected by reversing the sequence; any of a series of alloys varying in nickel and chromium could satisfy the conditions of maximum corrosion. The selection then could be based on other considerations, i.e., availability, economics, strength, etc.

Use of the Pearson Bridge in Corrosion Inhibitor Evaluation by E. J. Simmons. *Corrosion*, Vol. 11, No. 6, 255t-260t (1955) June.

Questions by James G. Jewell, Pittsburgh, Pa.:

1. Do your experiments indicate that changes in solution pressure and polarization emf as well as film resistance contribute substantially to the potential changes detected by the Pearson Bridge?

2. To what extent does the metal potential drift over a period of several hours when the applied current and inhibitor concentration are held constant?

Replies by E. J. Simmons:

1. No attempts have been made to determine the contribution of solution pressure to the electrode potential changes detected with impressed current. As pointed out, it is recognized that changes in polarization emf must certainly contribute to the observed shift, but to what extent has not been determined. Preliminary experiments with an external bridge which isolates the effect of film resistance show promise of being able to separate the resistive components from the polarization potential components in this shift.

2. No observations of metal potential drift with constant inhibitor concentration and constant impressed current have been made. Potential measurements are taken as soon after the crude oil-water mixture separates as a fairly stable reading can be obtained, usually after two to five minutes. The current is removed and the mixture stirred immediately thereafter until the next reading is taken. What you are suggesting here may be the basis for further study but we have done nothing on it as yet.

Question by Walter F. Rogers, Gulf Oil Corp., Houston, Texas:

Pearson's method was designed originally to back out solution IR drops and to permit calculation of anode or cathode resistive films. Apparently the work presented has dropped consideration of these phenomena in favoring of measuring $\triangle E/\triangle I$ or E-Log I curves of anodes and cathodes. This can be done with much simpler equipment than required for Pearson's technique.

Reply by E. J. Simmons:

As pointed out, the technique described in the latter part of the paper, i.e., the observation of changes of $\triangle E/\triangle I$ with time can be performed without the complete Pearson Bridge circuit. Preliminary work done to arrive at this simplified method utilized the complete circuit. We find it convenient to continue to use the Pearson Bridge for these tests. Others wishing to perform them may wish to assemble only that part of the circuit which is necessary. We have not dropped consideration of any observed phenomena but have found that in the case of the highly specialized system described in the paper, solution resistance in the salt water is so low compared to the film resistance that corrections for IR drop therein are considered relatively unimportant. In cases where inhibitors show no film resistance by the simplified technique we always run the complete test by correcting for solution resistance to see if there is a measurable smaller film resistance. So far all inhibitors tested have shown either no measurable resistance or an appreciably high resistance.

Questions by J. D. Sudbury, Continental Oil Co., Ponca City, Oklahoma:

1. There is indirect evidence that some inhibitors are not so effective in oxygen containing systems. Have you been able to study this effect using the Pearson Bridge?

2. The NACE T-1K tentative method for screening inhibitors has assumed that only very rapidly adsorbing films of inhibitor are effective inhibitors. Field correlation with this test admittedly has been very good. Your paper stated that rapidly adsorbed materials are rapidly desorbed and that slowly adsorbed materials are slowly desorbed. We assume that the slowly desorbed materials are the most desirable inhibitors. How do we reconcile this with the T-1K conclusion that the fast inhibitors are the best inhibitors?

Reply by E. J. Simmons:

1. While we believe it is possible to study the effect of inhibitors in oxygen containing systems, we have made little effort to do so. We have made the observation, however, that in some early tests where we were less careful in the exclusion of oxygen the data obtained were somewhat different from those obtained in later tests where we believe oxygen was essentially excluded. The results also were more erratic in the former case. We feel that in this test, as well as in numerous types of others, the difficulty of this type of study is in the control of the environment rather than in the interpretation of test data.

2. We believe that only time will tell whether or not the seemingly opposed inferences of the two tests has any significance. Also we did not wish to leave the impression that all rapidly adsorbing materials were rapid desorbers and vice versa; we merely wanted to point out that in the few cases we have studied (three) this was the case. This phase of work is very time-consuming and we simply have not been able to devote enough time to it.

Carbon Anode Installed in Electric Cable Conduit by Howard L. Davis, Jr. *Corrosion*, Vol. 11, No. 7, 295t-298t (1955) July.

Discussion by Daniel R. Werner, Kansas City, Mo.:

In Table 1 the corrosion rate for copper is given as 45.8 pounds per ampere year. The electrolytic corrosion of metal can be expressed by the formula:

$$\frac{W}{T} = ZI$$

Where:

W = weight of metal in grams (453.6 grams = 1 lb.)
T = time in seconds
Z = electrochemical equivalent of the metal
I = current in amperes

For copper:

$Z = 3.2937 \times 10^{-4}$ for a valence of 2
$Z = 6.5875 \times 10^{-4}$ for a valence of 1

The corrosion rate for copper would be 45.8 pounds per ampere year for a valence of 1 and 22.9 pounds per ampere year for a valence of 2. It is my understanding that a valence of 2 generally is used where an exposure to soil is concerned.

Reply by Howard L. Davis, Jr.:

If copper with a valence of 2 and an electrochemical equivalent of 22.9 pounds per ampere year were used in Table 1, the electro-volumetric equivalent of copper then would be 71.5 inches^3 per ampere year. This is slightly better than iron in this respect. However, the proper valence of copper for use in a particular situation would depend on the elements in the environment and the ultimate reaction that occurs. This can be determined only by test in any given set of circumstances. However, for the purpose of Table 1, either valence is acceptable to show the advantage of using graphite for the duct anode.

Question by Albert L. Ayres, Newark, N. J.:

It has been noticed in similar installations that the time interval between the date of the installation of the anode and the date of the duct survey has considerable bearing on the potential readings. What was the time interval between the date of installation and the date of the duct surveys in Figure 6?

Reply by Howard L. Davis, Jr.:

The duct survey data shown in Figure 6 was made one week after the anode system was energized. It is planned to make a re-survey two years after installation. It is likely that after two years of operation the current output of the anode may be reduced.

Question by Douglass T. Rosselle, Atlanta, Ga.:

The paper states that tests indicate the cable was protected. Have any corrosion failures occurred since the system was installed?

Reply by Howard L. Davis, Jr.:

There have been no corrosion failures since the system was placed in operation.

Question by J. J. Pokorny, Cleveland, Ohio:

How did you determine that a long distributed anode is necessary? Was it assumed that remote ground beds are necessary or had some ground beds been tried in close proximity to the duct line which did not work? In Cleveland we have been able to protect long isolated sections of duct line by means of simple ground beds placed in the bottom of manholes using very small currents of one to two or three amperes from a rectifier.

Costs are not discussed in the paper but it seems that the distributed graphite anode line would be very expensive, especially when it is considered that the anode line consumes a duct and in that proportion reduces the utility of the duct line for carrying cables.

Reply by Howard L. Davis, Jr.:

As indicated in the text, the use of remote ground beds as sacrificial anodes is impractical in urban areas. The use of point anodes in close proximity was not tried inasmuch as the duct bank was under a cobblestone and concrete paving. Previous experience with completely submerged duct lines has shown that to obtain protection in the middle of a section with anodes in the adjacent manholes creates objectionably high cable sheath-to-environment potentials near the manholes.

The installed cost of the entire system was $2.25 per foot. This cost does not include the duct occupied by the anode. Where an anode must be installed in an existing plant, there seems to be no choice but to give the use of a single duct in order to properly operate the remainder of the cables.

The Electrochemistry of Inhibitor Action by R. B. Mears. *Corrosion*, Vol. 11, No. 8, 362t-364t (1955) Aug.

Question by F. E. Kulman, Consolidated Edison Co. of N. Y., Inc., New York, N. Y.

When atomic hydrogen forms on an iron cathode, causing polarization, does this polarization *increase* the electrical resistance of the corrosion circuit? Or is the main effect a change in electrode *potential?*

Reply by R. B. Mears:

When hydrogen forms on an iron cathode, the electrode potential changes. This is probably the result of both an increased IR drop in the cathode film and a back emf resulting from hydrogen overvoltage. The latter development is analogous to concentration polarization.

Question by H. Hyde, Charles Engelhard, Inc.:

Could you describe the basic theory of polarization of a steel surface in sea water when cathodic protection is achieved by impressed current? Do hydrogen bubbles form on the steel?

Reply by R. B. Mears:

When steel is cathodically protected in sea water,

the cathode potential is affected by at least three factors:

1. At the start, a hydrogen film forms on the steel surface.
2. As electrolysis proceeds, the liquid layer adjacent to the steel surface becomes strongly alkaline, so that the cathode becomes exposed to an electrolyte that differs greatly in composition from sea water.
3. Eventually, a layer of calcium and magnesium salts are built up on the cathode surface. This acts somewhat like an inert coating to help protect the steel.

Questions by E. T. Worden, The Stanley Works, New Britain, Conn.:

1. Do you find that you fail to obtain the best benefits of a volatile corrosion inhibitor when it is used in a paper wrap surrounding an oiled, phosphated steel part? Does the oil absorbent paper absorb and prevent best protection by the oil and does the oil and the phosphate interfere with the action of the volatile inhibitor?

2. How can you prevent the formation of "heat" or "coonskin" stains on sheet steel? (These stains are formed on freshly pickled sheets after the sheets are stacked or the strip is coiled.)

Replies by R. B. Mears:

1. I know of no data to aid in directly answering your questions. From other work, I believe that if vapors from the volatile corrosion inhibitor contact all areas of the steel surface, corrosion would be inhibited. As far as I know, a phosphate coating or an oil coating on the steel will not reduce the effectiveness of the volatile inhibitor.

2. I am not familiar with the terms "heat" or "coonskin" stains. Freshly pickled stacked sheets or coils will rust unless they have been rinsed, treated in an alkaline or inhibited solution, and thoroughly dried prior to stacking or coiling.

Question by C. S. Reichard, Socony Mobil Oil Co., Inc.:

Has instrumentation been developed which would allow field measurements to evaluate effectiveness of presently used inhibitors?

Reply by R. B. Mears:

I know of no instruments that will permit evaluation of effectiveness of presently used inhibitors under field conditions. Such an evaluation is, of course, possible under laboratory conditions.

Question by E. F. Marantz:

Why is the use of hexametaphosphate superior to either di, tri, or mono phosphate as an inhibitor in solution?

Reply by R. B. Mears:

I do not believe that sodium hexametaphosphate is superior to mono, di, or trisodium phosphate as an inhibitor under all conditions. Hatch's work (G. B. Hatch and O. Rice, *Ind & Eng Chem*, **37**, 752, 1945) has indicated that in a sodium chloride solution, sodium hexametaphosphate is not an effective inhibitor. Apparently, calcium or magnesium salts must be present in order for the sodium hexametaphosphate to be effective. Such salts are present in most natural fresh waters.

Question by A. J. de Bethune, Boston College:

You showed that chromate polarizes the anodes on aluminum and depolarizes the cathodes. What is the mechanism or mechanisms?

Reply by R. B. Mears:

Chromates increase anodic polarization, probably because they form or strengthen the film on the anode surface. They depolarize the cathodes, probably because they are oxidizing agents. Dissolved oxygen or hydrogen peroxide also causes depolarization of the cathodes. Manganese dioxide is actually used for this purpose in dry cells.

Miscellaneous question:

Which is the more desirable inhibitor—one that causes anodic polarization or one that causes cathodic polarization?

Reply by R. B. Mears:

Either type of inhibitor can be equally safe and effective, provided it does not reduce the anodic area more rapidly than it reduces the corrosion current. In other words, as long as the total corrosion current is reduced and the anodic current density is not increased, the inhibitor will be safe. This desirable result can be achieved either by an inhibitor that causes anodic polarization or by one that causes cathodic polarization.

Principles Applicable to Oxidation and Corrosion of Metals and Alloys by W. W. Smeltzer. *Corrosion*, Vol. 11, No. 9, 366t-374t (1955) September.

Question by Andrew Dravnieks, Standard Oil Co. (Indiana), Whiting, Indiana:

There is evidence that in oxides of Me_2O_3 type of oxygen ion is the diffusing species. What is the reason to believe that in Al_2O_3, Al^{+++} is diffusing?

Reply by W. W. Smeltzer:

It is believed that aluminum forms a metal excess oxide film which thickens by diffusion of aluminum ions and electrons to react with oxygen at the oxide/oxygen interface because its oxidation rate is largely independent of oxygen pressure and ultraviolet radiation (references 18 and 19 of the text). Because the ionic charge of the diffusing aluminum ion is unknown, investigators assume its most common value of +3.

Economics of Painting by J. E. Cogshall. A paper presented at the Northeast Region Meeting, New York City, May 9-11, 1955. The paper has not been published in *Corrosion*.

Question by R. H. Ludre:

Are there any disadvantages to rolling the primer in the case of: 1) Wirebrushed surfaces, 2) Sandblasted surfaces?

Reply by J. E. Cogshall:

While it is generally accepted that brushing a primer will avoid "bridging" over pit holes and rust spots on steel surfaces, it has been found that roller application of the primer to both wirebrushed surfaces and sandblasted surfaces will provide an application relatively free of such "bridging." In this respect it approaches the quality of a primer application made by brushing.

Question by E. Heinzelman, Oakite Products Inc., New York, N. Y.:

In your paper you stated that sandblasting was the best method of preparation of metal surface for painting. Have you compared sandblasting with other treatments such as chemical (phosphoric acid) or wash primers?

Reply by J. E. Cogshall:

The use of a wash primer as a method of surface preparation is controversial. Many consider the use of a wash primer as a surface treatment in conjunction with surface preparation. Used in this latter manner the wash primer can be quite effective. This does add another step to the coating application.

The use of chemical treatment for surface preparation may be useful in eliminating a very light rust from a steel surface. Where heavy deposits of corrosion products together with oxidation of the steel form such a heavy deposit, chemical cleaning becomes practically impossible on erected structures. On these surfaces then, a thorough mechanical cleaning is required. Sandblasting is certainly one of the best of the mechanical cleaning methods.

Question by H. S. Preker, Bushes, Navy Department, Washington, D. C.:

What is the best surface pretreatment over galvanized surfaces?

Reply by J. E. Cogshall:

The best surface pretreatment over galvanized surfaces, in our experience, is a solvent cleaning. A solvent such as methyl ethyl ketone or carbon tetrachloride should be used to avoid leaving a secondary oily film on the surface. The galvanized surface is then acid etched, using a mild phosphoric or acetic acid as an etchant. This will provide a galvanized surface that has a definite "tooth" that will give the best paint adhesion. Here again we want to emphasize that we are talking about maintenance painting surface preparation, normally done in place in the field.

Question by F. T. Radecke, Shell Oil Co.:

There was no mention of inhibitive primers—does this mean you do not recommend them? Brush applications are the most expensive, spraying the least expensive and rolling of intermediate cost. Spraying is the most uniform and has the highest film build. Economics are not in accord with methods other than spraying; why not develop coatings that will spray?

Reply by J. E. Cogshall:

The use of inhibitive type primers are strongly recommended. They were mentioned, but perhaps not emphasized, in the course of our talk.

In maintenance painting there is frequent resort to the use of brush and roller application. On large open surfaces such as tank sides the use of spray equipment may do the most rapid job. Frequently for smaller jobs the set-up time involved in spray painting may result in a less rapid application.

Questions by E. Domingo:

1. How is a surface painted with silicone coating prepared for repainting?
2. What is your opinion of the use of rust preventer—selenium?

Replies by J. E. Cogshall:

1. In our experience with high temperature silicone coatings the surface preparation required for successful application is a thorough wirebrushing. This removes all loose rust and loose paint particles.
2. We have no specific experience in the use of this type product. For this reason we cannot express an opinion.

Question by R. B. Mears, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.:

How does pickling or flame cleaning compare with sandblasting? How about surface conversion coatings or chemical treatments as preparation for painting?

Reply by J. E. Cogshall:

Pickling, if properly handled, can be equally as effective as sandblasting as a surface preparation. For acid pickling, careful and thorough rinsing normally is required. The use of acid pickling in maintenance painting applications, which normally are field applications, has not proved overly successful.

Flame cleaning as a method of surface preparation does not in all cases provide a surface comparable to that of sandblasting. Sandblasting will remove all rust, rust scale, corrosion products and millscale from a steel surface. Flame cleaning will "pop off" of the surface loose and moderately tight scales by a differential temperature procedure. In some cases, tightly adhering millscale will not be removed by flame cleaning. It generally is necessary to include wirebrushing in the surface preparation procedure following the flame cleaning.

Surface conversion coatings or chemical treatments, as applied to maintenance painting, appear to offer little by way of extending service life to a maintenance coating application. In other words, an additional step or operation is added to a maintenance coating application without an additional resulting benefit.

Question by E. T. Worden, The Stanley Works, New Britain, Conn.

Does a roller application of paint to an outside previously painted wood structure provide as satisfying a bond as a brush application?

Reply by J. E. Cogshall:

In our experience the use of the roller to recoat a previously painted wood structure will provide an equal bond to that of a brush application. This should be qualified by stating that the surface preparation of an old painted surface should be adequate to permit a bond between the two layers of paint. In other words, any dirty or oily film that may prevent bonding should be removed. There are a variety of means of achieving this, including solvent wiping.

Miscellaneous questions:

1. Do you find that the 5-mil film thickness, so generally advocated recently, is inadequate for the protection of equipment in many areas of a chemical plant, particularly where there is rather severe spillage and splashing?

2. Welds on flat surfaces and corners cannot be reached by the even pressure of roller coating. If this requires brush painting, has not the use of roller coating been overemphasized, as few surfaces are as even over a large surface as are house walls where this method has met with success? Doesn't roller coating put on a thinner film than brush painting?

3. In maintenance painting where sandblasting cannot be used, what other mechanical tools do you recommend for surface preparation?

Replies by J. E. Cogshall:

1. This is quite true. In certain plant areas where there is a particularly aggressive atmosphere, usually typified by strong fume condition together with high humidity complicated by the entrainment of the corrosive liquid, greater coating thicknesses than the 5-mil thickness are required. In these cases, 10 to 15 mils may be required before adequate protection is obtained. Here again the high build coating materials are the choice to apply from an economic point of view. The 5-mil film thickness principle holds good in the more general plant areas where relatively dry fume conditions are prevalent.

2. In rolling solvent type coatings it has been found that a more uniform, heavier deposition of coating is placed on the surface. Using a roller with a ⅜-inch nap provides an excellent application tool for covering such irregularities on a surface as welds, etc. It can be generally stated that roller application will give a better coating deposit in all accessible surfaces, including sharp edges, pits and prominences than will a brush application. Naturally a roller application must be supplemented with brush application in those areas not accessible to a roller. Such areas as acute angles in structural steel in hidden corners must be coated by means supplementary to the roller application.

3. There are a number of mechanical tools, other than sandblasting equipment, that are used successfully for surface preparation. Such tools include power driven wire brushes, rotary wheel abrader equipment, mechanical vibrators, and in certain cases grinding wheels. These tools, either singly or in combination, in many cases can give satisfactory surface preparation.

Corrosion by Valve Packing. By L. M. Rasmussen, *Corrosion*, Vol. 11, No. 4, 155t-160t (1955) Apr.

Question by Frank L. LaQue, The International Nickel Co., New York, N. Y.:

One might question the significance of the open circuit potential measurements used by the author to indicate the resistance of stainless steels to corrosion under packing. The significance of such measurements might be increased and interpretation made easier if the experimental setup were to include some means for developing a crevice on the stainless steel surfaces. Break-down of passivity in such a crevice would be reflected by a substantial shift in the potential.

The exact function of zinc in the combinations with graphite was not clear. It might be expected that the possible effect of zinc as a protective galvanic anode would be dissipated by its galvanic action with the associated graphite. From this, it might follow that if mica were to be substituted for graphite in such combinations, the zinc would have a better chance to exert its expected galvanic protective action.

It would be reasonable to expect that zinc could be damaging to stainless steel when used in packings for service at elevated temperatures, especially if the temperature were to be high enough to vaporize the zinc.

Finally, it would be of interest to know if improved packings based on this research program are available.

Reply by L. M. Rasmussen:

The open potential measurements were made only to indicate which steels, if any, would be preferable as stem material when exposed to a similar electrolyte as obtained under hydrostatic test and dead storage of a valve. Some of the steels and titanium were used as stem materials in valves hydrostatically tested and stored. Titanium which showed excellent results in the open potential measurements also was excellent as a valve stem under the storage conditions mentioned.

The function of the zinc in combination with the

graphite is that of a protective galvanic anode. Valve stems stored in contact with wet packing having graphite as a lubricant will pit; the presence of zinc retards this pitting appreciably. Once the zinc has been consumed no protective galvanic anode would be present and pitting could be expected. However, the problem of pitting of valve stems is a condition of dead storage. As pointed out in the paper, if the valve were hydrostatically tested and immediately placed in service, stem pitting would not be encountered as it is when the valve is hydrostatically tested and stored.

We have made a number of service tests using mica in place of graphite and have found that when a leak occurs through the packing there is a definite tendency for the mica to "blow out." Graphite, however, does not exhibit this characteristic.

With the trend toward higher steam temperatures the action of zinc or stainless steels at these temperatures definitely would be a point to consider.

Improved packings based on this research as well as further investigation by the cooperating packing manufacturer have produced packings which definitely will inhibit pit corrosion during the dead storage period. Such packings are available from the manufacturer.

Question by F. N. Alquist, Midland, Michigan:

Did you test with distilled or deionized water?

Reply by L. M. Rasmussen:

Tests were conducted with deionized water in two test locations; distilled water was used in one location and tap water in all three locations. The deionized water was tested and it showed an impurity concentration of 0.2 ppm or less.

Discussions to technical articles appear in the June and December issues only when they do not immediately follow the article to which they pertain. Discussions received from December through May will appear in the June issue and those from June through November in the December issue.

Technical Committee Activities

T-2C Weighs Cathodic Protection Anomalies At Meetings in Houston and Niagara Falls

Instances in which the —0.85 volt criterion proved to be an unreliable indication of cathodic protection of underground structures were discussed at meetings of T-2C in October and November.

Covered also at the Houston meeting October 19 were polarization characteristics of graphitized and new cast iron pipe sections buried in 500-ohm continuously wet soil. Preliminary tests indicate considerably more current is required to polarize graphitized cast iron than new. Work continues on the project.

Significance of the —0.85 volt criterion at ground surface over a pipe in 20,000 to 30,000-ohm soil was discussed also at Houston. Instances were cited where severe corrosion occurred in high resistivity soils where the —0.85-volt criterion was recorded. It was reported a potential gradient of several hundred millivolts may exist between ground surface and pipe receiving the current.

Electrode Position Tests

L. P. Sudrabin, Electro Rust-Proofing Corp., chairman of T-2C reported on a project underway in eastern Pennsylvania where a 240-foot section of pipe is buried with zinc electrodes attached to represent different sized anodes. The test is designed to show importance of reference electrode position, evaluate the log potential current density break relationship, the earth current meter and use of null methods. Several committee members participated in final readings and tests November 5 and 6. Results are expected to be available for the March NACE Conference in New York.

At a session of T-2C in Niagara Falls during the recent Northeast Region Meeting there, considerable discussion evolved concerning the reliability of soil resistance measurements in anticipating corrosion. The concensus was that it is extremely difficult to prove protection in high resistivity soils and that the mere presence of high resistivity soil is no guarantee corrosion will not occur.

Project Probes Anomaly

A member described a project underway to determine when a corroding condition exists and what is happening near the pipe when it does. Initial work indicates it is not necessary to test all around the pipe because under corrosive conditions current flow will be found at the top of the pipe regardless of the location of the cell.

Further evidence was presented that corrosion can occur even when the structure apparently has the required —0.85 volt potential versus a reference electrode. In one case a leak occurred in the coated section of a partially coated and partially bare pipe even though a rectifier had maintained a —0.85 volt differential for three years. The enamel coating was in good condition and no reason for the failure could be found.

Another instance was related in which a protective current of the required negative voltage was measured over a pipe in soil of 200,000 to 300,000-ohm resistance and failure still occurred.

Measurements on Vertical Piling

Measurements on a vertical piling in which reference electrodes were placed 127 feet below the surface adjacent to the pile were described. Measurements under these conditions are analogous to those made in oil well casings.

One member said, answering a question regarding current density required to protect oil well casings, that current density for protection might be greater for the local cell than for the gross cell potential as measured with downhole instruments. Current required to neutralize cells at 1200 feet is not materially reduced after one day's application and cells at 6000 feet may take a week to polarize.

Eight Long Range Objectives Are Outlined for T-4B-2

Eight long range objectives have been outlined for Task Group T-4B-2 on Cathodic Protection of Cable Sheaths. They are:

1. Protective criteria and determination of maximum and minimum allowable potentials; consideration of the avoidance of cathodic corrosion.
2. Ground bed or anode location and maintenance of proper distances to lead cable sheaths.
3. Ground bed design and characteristics.
4. Characteristics of galvanic anodes used to protect cable sheaths.
5. Sheath grounding cells.
6. Installation and design of galvanic anode systems.
7. Rectifier characteristics used to protect cable sheaths.
8. Use of insulating joints and insulation of cable sheaths.

During three years the committee has distributed and received replies to two questionnaires. Returns are now being compiled for an interim report on cathodic protection of cable sheaths.

T-4B Cites Conditions Causing Concentration Cells

Conditions which will produce differences in the concentration of an electrolyte, the mechanism of concentration cell corrosion and two detailed examples of concentration cell corrosion are described in the Third Interim Report of T-4B on Corrosion of Cable Sheaths. The report, now complete and being considered for approval by letter ballot, is titled "Examples of Concentration Cell Corrosion of Lead Cable Sheaths."

Control Practices in 29,187 Wells in 676 Fields Surveyed

A consensus of corrosion control measures of 19 companies on 29,187 oil wells in 676 fields is contained in a report soon to be submitted for approval and publication. The report titled "Field Practices Regarding Water Dependent-Sweet Oil Well Corrosion," was presented at a meeting of T-1 on Corrosion in Oil and Gas Well Equipment October 18 in Houston.

J. T. Payton, The Texas Co., Houston, chairman of Task Group T-1C-1 on Field Practices, presented the report, explaining it was a summary of replies received from the 19 companies.

Equipment failure is the indisputable criterion of oil well corrosivity and the report indicates that most operators have established limits for corrosion-detection criteria on percent of eater produced, iron concentration, coupon corrosion rate, caliper survey and equipment failure frequency.

Sections of the report are:

Well Equipment—Including methods and equipment for using inhibitors and special materials with chemicals in flowing wells, pumping wells and gas lift wells.

Special Tubing Materials—Including plastic coated tubing and special alloy tubing.

Chemical Treatment—Including type of chemical used, methods, means of rating effectiveness.

Revision of Coating Standard Now Under Ballot

A revision of the coating leakage conductance standard has been approved for submission to letter ballot by Unit Committee T-2D on Standardization of Procedure for Measuring Pipe Coating Leakage Conductance. The committee met during the South Central Region sessions in Houston October 19.

Studies are underway now by groups assigned as follows: Short insulated sections of low conductance, inaccessible locations, such as water crossings; lines where marked polarization interferes with measurements and pipe in a stray current field.

Coal Tar Coatings Report Submitted for Approval

Recommended Specifications and Practices for Coal Tar Coatings, a report of Unit Committee T-2G on Coal Tar Coatings, was approved October 18 at Houston. The report has been submitted to the chairman of group committee T-2 for approval.

The report covers long term performance, primers and physical properties required for three types of coal tar coatings.

SCENES AT NORTHEAST REGION'S NOVEMBER MEETING at Niagara Falls. 1. Standing, left, T. J. Finnegan, Niagara Mohawk Power Corp., Buffalo; right, J. F. Mason, Jr., Inco, New York; sitting, left to right, W. G. Godfrey, Niagara Mohawk Power Corp., Buffalo; H. S. Ingham, Metallizing Engineering Co., Westbury, N. Y., A. W. Tracy, the American Brass Co., Waterbury, Conn.

2. Left to right, Charles W. Beggs, Public Service Electric and Gas Co., Newark; Ted Kennedy, Jr., The Trenton Corp., Ann Arbor, Mich.; F. E. Costanzo, Manufacturers Light and Heat Co., Pittsburgh and N. T. Shideler, Pittsburgh Coke & Chemical Corp., Pittsburgh.

3. Left to right, Stuart H. Gates, Southern Bell Telephone and Telegraph Co., Louisville, Ky.; John M. Fouts, New York Telephone Co., Buffalo; Lewis P. Aker, Louisville Gas and Electric Co., Louisville, Ky.

4. Scene at the annual banquet of Northeast Region.

5. Left to right, George E. Best, Mutual Chemical Div., Allied Chemical and Dye Corp., Baltimore and Vernon B. Pike, Bell Telephone Laboratories, Murray Hill, N. J.

6. Left to right, W. A. Sinclair, The Detroit Edison Co., Detroit; T. J. Maitland, American Telephone and Telegraph Co., New York.

7. Marshall E. Parker, consultant, Houston; Norman P. Peifer, The Manufacturers Heat and Light Co., Pittsburgh; Carl A. Erickson, Jr., The Peoples Natural Gas Co., Pittsburgh and Lester M. Plym, Illinois Bell Telephone Co., Chicago.

8. Standing, left to right, A. B. Campbell, NACE Executive Secretary, Houston; T. P. May, Inco, New York City; E. G. Brink, American Viscose Corp., Marcus Hook, Pa.; F. E. Costanzo, The Manufacturers Light and Heat Co., Pittsburgh; J. E. Shields, Niagara Falls; sitting, W. F. Fair, Jr., The Koppers Co., Inc., Pittsburgh; Rob Roy MacLeod, Niagara Mohawk Power Co. and an unidentified representative of the city of Niagara Falls.

NACE News

Liaison Among Corrosion Committees Is Urged

Aid in Forming New Groups Is Proposed At Niagara Falls

An NACE technical committee to compile information, act in liaison among and assist in forming new cooperating committees among operators of underground plant is recommended by a group in Northeast Region. This suggestion, that NACE be asked to organize such a group, was unanimously approved at the end of a panel discussion on organized corrosion committee operations.

This was one of the outstanding developments of the October 31-Nov. 3 regional meeting at Niagara Falls. Registration for the 4-day session was 292. NACE Technical Committees T-2C on Minimum Current Requirements for Cathodic Protection and T-4B-1 on Corrosion of Lead and Other Metallic Sheaths for Power and Telephone Cables met October 31.

Advantages Are Cited

Stewart H. Gates, Southern Bell Telephone and Telegraph Co. and Lewis P. Aker, Louisville Gas & Electric Co., Louisville, Ky., who conducted the panel on corrosion committee operations, cited some of the advantages of organized committee operation. Specific cases were cited where committees produced harmonious working relationships, equitable division of costs and general cooperation among operators of underground plant engaged in the struggle to minimize corrosion.

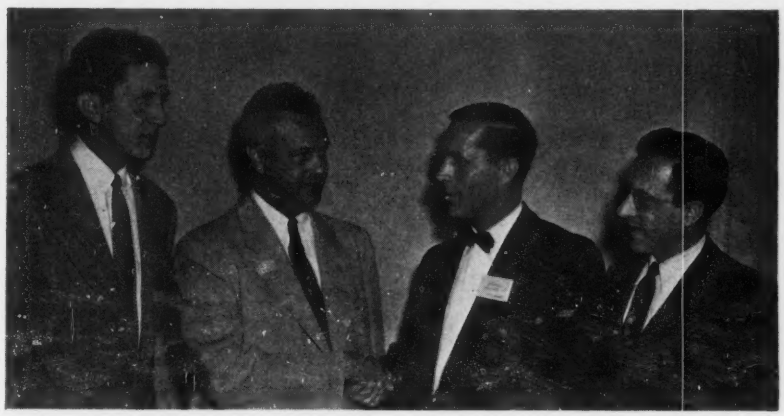
Besides the fifteen technical papers, four panel discussions were held as follows: Fundamentals of Corrosion and Fundamentals of Corrosion Testing on Underground Plant, George E. Best, Mutual Chemical Division, Allied Chemical and Dye Corp., moderator. Protective Coatings for Underground Structures, T. J. Maitland, American Telephone and Telegraph Co., New York, moderator. Corrosion in Power Generating Plants and Stations. William G. Godfrey, Niagara Mohawk Power Co., Buffalo, moderator. Cathodic Protection, Norman Peiffer, Manufacturers Light and Heat Co., Pittsburgh.

Mr. Best, NACE Director representing Northeast Region, opened the meeting with brief remarks November 1.

J. M. Fouts, New York Telephone Co., Buffalo, program chairman said the meeting was successful from all points of view.

Power Company Official Speaks

Rob Roy Macleod, vice-president of Niagara Mohawk Power Corp. was principal speaker at the November 2 banquet. He cited the need for engineers to have a strong religious faith. Keys to the city of Niagara Falls were presented to W. R. Wardrop, Metal Cladding, Inc., chairman of Niagara Frontier Section. A fellowship hour preceded the banquet.



NEWLY ELECTED AND OUTGOING OFFICERS of Niagara Frontier Section are (left to right): Walter A. Szymanski, Hooker Electrochemical Co., Niagara Falls, N. Y., secretary-treasurer elect; John M. Fouts, New York Telephone Co., Buffalo, chairman-elect; William R. Wardrop, Metal Cladding Inc., Buffalo, outgoing chairman; E. H. Caldwell, Oldbury Electrochemical Co., Niagara Falls, vice-chairman-elect.

Rounded Technical Program, Social Events Feature Southeast Region's Miami Meeting

A well-rounded technical program and a varied social and entertainment program featured the Southeast Region's November 10-11 meeting at Key Biscayne Hotel, Miami. A social hour was held November 10 and a banquet and dancing November 11.

The technical program, arranged by J. B. Prime, Jr., Florida Power and Light Co., was:

Thursday, November 10

Atomic Energy and Light Energy: Reactor Development, John C. Robinson, Chief of Engineering Development Div., Atomic Energy Commission; Solar Energy, Forrest L. Thorpe, Southern Bell Telephone & Telegraph Co.

Process Industries: Aluminum, Edward T. Wanderer, Aluminum Company of America; Stainless Steel, John M. Perryman, R. D. Cole Co.; Condenser Tubes, D. S. Neill, Bridgeport Brass Co.

Marine Corrosion: Atmospheric, Tidewater and Underwater Corrosion, T. P. May, The International Nickel Co.; Corrosion Problems of the Small Boat Owner, Sigmund Miller, Marine Laboratory, University of Miami.

Panel Discussion: All Thursday, speaker, Herbert C. Van Nouhuys, Moderator.

Friday, November 11.

Protective Coatings: Surface Preparation, A. J. Liebman, Pitmar Centrifugal Machine Corp.; New Development. Evaluation and Inspection, J. G. Lacy, Amercoat Corp.; Engineered Coatings, Harry Backsondale and Mike Randall, Synco Corp.

Cathodic Protection: Corrosion Causes, Cost and Control, T. W. Bostwick, City of Jacksonville, Fla.; New Developments in Cathodic Protection, M. C. Miller, Ebasco Services, Inc.; Ground Beds, J. P. Oliver, National Carbon Co., Division of Union Carbide and Carbon Corp.

Panel Discussion: All Friday speakers, Herbert C. Van Nouhuys, Moderator.

Also on Friday afternoon the following motion pictures were shown: Aluminum on the Skyline, At Dawn's Early Light, The Man with One Thousand Hands, Manufacture of Valves. A display of corrosion mitigation equipment by instrument manufacturers was held.

Sabine-Neches Refinery Corrosion Panel Scheduled

A panel discussion on refinery corrosion problems will be featured at the December 8 meeting of Sabine-Neches Section. The section will convene at Little Mexico Restaurant, Orange. C. A. Murray, Pure Oil Co., is program chairman.

J. Glen Lacy, Amercoat Corporation, discussed requirements of successful coatings at the October 27 meeting. The session, held at Little Mexico Restaurant, Orange, attracted 35 members and guests. The speaker explained advantages and limitations of basic coating types, effect of cathodic protection and the uses and benefits of coating thickness measuring and holiday detecting instruments.

AT HOUSTON SOUTH CENTRAL REGION meeting October 18-21 a moment of relaxation is enjoyed by Alvan E. Richey, Cathodic Protection Service, general chairman; W. F. Fair, Jr., Koppers Company, Inc., NACE vice-president; Frank L. Whitney, Jr., Monsanto Chemical Company, NACE president, and J. E. Loeffler, Thornhill-Craver Co., South Central Region chairman.

Concentrated Interest Is Shown in Technical Papers

Concentrated attention was given to the 33 papers presented October 18-21 during the 1955 South Central Region meeting at the Shamrock-Hilton Hotel, Houston. Large—sometimes capacity—audiences heard the papers presented in 10 symposia.

The technical program shared the conspicious success of the remainder of the meeting. The greatly increased attendance, which caused overcrowding of technical committee meetings during the first two days of the sessions, resulted only in larger than usual audiences at the symposia.

South Central Region Elects Nee Chairman

John W. Nee, Briner Paint Manufacturing Co., Inc., Corpus Christi, Texas is the 1956 chairman of South Central Region. The election of Mr. Nee and other regional officers was announced during the annual regional business meeting October 21 by J. E. Loeffler, Thornhill-Craver Co., Houston, retiring chairman.

Jack P. Barrett, Stanolind Oil and Gas Co., Tulsa, was elected vice-chairman and J. C. Spalding, Jr., Sun Oil Co., Dallas, was named secretary treasurer. J. A. Caldwell, Humble Oil and Refining Co., Houston was named assistant secretary-treasurer. Their terms of office begin January 1.

San Antonio to Be Host to 1956 Regional Meeting

San Antonio was chosen as the site for the 1956 South Central Region meeting during the October regional gathering in Houston. Transfer of the meeting to San Antonio was approved on application of representatives of San Antonio Section when previous arrangements to hold the meeting at Beaumont were cancelled.

The 1957 meeting of the region will be held at the Skirvin Hotel, Oklahoma City, during the first week in October, J. E. Loeffler, regional chairman announced at the annual regional business luncheon October 21.

SPEAKERS at symposia presented at Houston meeting in October are shown: Left: E. V. Kunkel, Celanese Corp., Bishop, Texas, talks at the Process Industries Symposium on "Corrosion in Processing Acetic Acid and Related Compounds"; right, Sidney V. Smith, Napko Paint Co., tells a group at the Protective Coatings Symposium about organization of the Houston Painting Club and what its aims are.

Six Past Chairmen Are Honored at Luncheon

Six past chairmen of South Central Region were awarded certificates of appreciation and two certificates were prepared for presentation to deceased past chairmen at the annual business meeting of the region Friday, October 21 at the Shamrock-Hilton Hotel, Houston. The luncheon meeting was the final event of the 1955 South Central Region meeting at the hotel, which attracted 1016 registrants.

J. E. Loeffler, Thornhill-Craver Co., regional chairman who presided at the annual business meeting briefly outlined the contribution each past chairman had made to the National Association of Corrosion Engineers. He presented certificates personally to M. C. Fleming, Phillips Petroleum Co., Bartlesville, Okla., Harry E. Waldrip, Gulf Oil Corp., Houston and H. L. Bilhartz, Production Profits, Inc., Dallas. Certificates will be forwarded to A. N. Horne, Texas-Empire Pipe Line Co., Tulsa; T. R. Statham, Magnolia Pipe Line Co., Dallas; and Nathan Shofer, Koch Engineering Co., Wichita, Kan., who were unable to be present.

Certificates for Donald B. Good and George A. Mills, both deceased, will be presented to their widows on behalf of the region.

Campaign Seen to Get National Conference In Houston in 1959

"Houston Section will work with trustees of South Central Region in a continuing effort to get a national meeting of the National Association of Corrosion Engineers in Houston at the earliest date," said Alvan E. Richey, Cathodic Protection Service, Houston at the conclusion of the October South Central Region meeting at Houston. Based on the success of the regional meeting, Mr. Richey said he believes a national meeting in Houston would outdraw in registrations any previous meeting the association has held.

The October 18-21 regional meeting exceeded advance estimates of registration by more than 40 percent. This resulted in exceptional attendance at committee meetings and at technical symposia. Social events were equally popular. Mr. Richey was high in praise of his assistants for their work in making the gathering successful beyond expectations.

Mr. Richey, who was general chairman, said L. G. Sharpe, Napko Paint Company, Houston, Houston Section trustee, would solicit the cooperation of the regional board of trustees in getting the national meeting for Houston in 1959.

Whitney Forecasts Greater NACE Activity to Come

More and better technical papers at meetings, accelerated committee activity and larger budgets for research were forecast for the National Association of Corrosion Engineers by Frank L. Whitney, Jr., Monsanto Chemical Co., St. Louis, NACE president before some 300 October 21 at the annual South Central Region business meeting. Mr. Whitney, who also presented a technical paper in the Recirculated Water Symposium, said the NACE was not going to stand still and that it would continue to seek its goal of unified control of corrosion.

Mr. Whitney emphasized the important work of the technical committees in NACE. "Technical committees are the backbone of NACE," he said, predicting that the committees would progress from the voluntary type of activity as at present to a more formal, self-sustaining role.

Waldrip Elected to Regional Directorship

Harry E. Waldrip, Gulf Oil Corp., Houston has been elected director representing South Central Region on the board of directors of the National Association of Corrosion Engineers. His term of office will begin March 16, 1956. Mr. Waldrip, who was regional chairman in 1953, has held almost all regional offices. He succeeds Derk Holsteyn, Shell Oil Co., Houston.

Verink Is Guest Speaker

E. D. Verink, Jr., Aluminum Company of America, New Kensington, Pa. spoke to 10 members and two guests of Genesee Valley Section October 18 on "Combating Chemical Corrosion with Aluminum."

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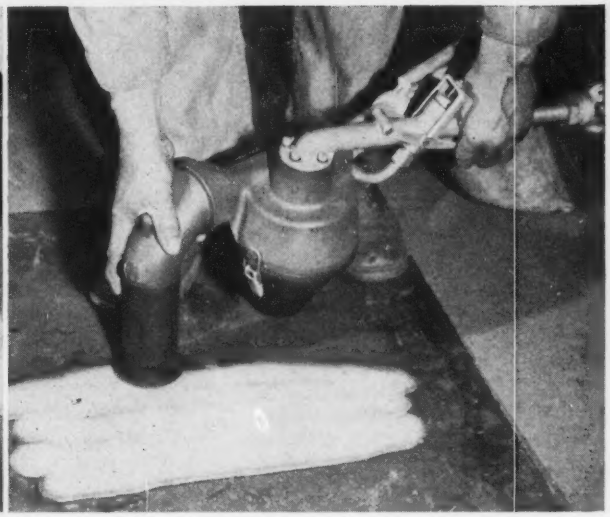

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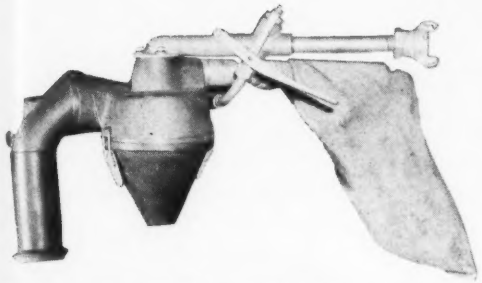

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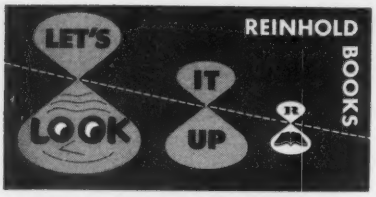

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Oil Field Structures, Materials, Ocean-Going Ships, Pipe Lines Covered at San Francisco

Symposia on corrosion of oil field structures, materials, ocean going vessels and pipe lines featured the November 17-18 meeting of Western Region at the Sir Francis Drake Hotel, San Francisco. Meetings of T-5A-1 on Sulfuric Acid Corrosion, T-2H on Asphalt Type Pipe Coatings and T-4F-1 on Water Meter Corrosion were held also.

Social events included a Fellowship Hour and the conference banquet on November 17. R. S. Treseder, Shell Development Co., was conference chairman and D. Roger Loper, Standard Oil Co. of California, program chairman for the event. Others responsible for the meeting included: R. E. Deshon, Republic Supply Co. of California, publicity chairman; T. J. McCormick, McCormick's Chemical and Inspection Co., committee member; G. J. Puckett, Dow Chemical Co., registration chairman; E. E. Bunton, Pacific Metals, facility arrangements chairman.

R. A. Kronmiller, The Flox Co., Inc., hospitality chairman, with a committeeman, H. R. Strickland, Haynes Stellite Co.; R. E. Hall, Union Oil Co., Southern California liaison and T. J. Smith, Electric Steel Foundry, general arrangements.

The technical program was as follows:

Thursday, November 17

Symposium on Corrosion of Oilfield Structures, P. J. Raifsnider, Shell Development Co., chairman.

Factors Controlling Corrosion by Hydrogen Sulfide by R. S. Treseder, Shell Development Co.

Cathodic Protection for Control of External Casing Corrosion by John D. Sudbury, Continental Oil Co.

Corrosion Inhibitors for Control of Corrosion in Oil Wells by Preston W. Hill, Signal Oil and Gas Co.

Symposium on Corrosion Resistance of Materials of Construction, A. E. Storm, Tidewater Associated Oil Co., chairman.

Recent Laboratory and Field Experience with High Nickel Alloys for Corrosion Resistance by John Schley, Haynes Stellite Co.

Extra-Low Carbon Stainless Steels for Chemical Plant and Refining Equipment by J. R. Cunningham, Standard Oil Co. of California.

Friday, November 18

Symposium on Corrosion of Ocean Going Vessels, M. T. J. Garlinger, Military Sea Transport Service, U. S. Navy, chairman.

Pitting Corrosion of Tankship Internals by F. L. LaQue, The International Nickel Co., Inc.

Corrosion Protection of Vessel Hulls, by Arthur Burns, Devoe & Raynolds Co., Inc.

Corrosion of Piping and Condensers Aboard Ship by C. L. Bulow, Bridgeport Brass Co.

Symposium on Pipe Line Corrosion, J. K. Ballou, Standard Oil Co. of California, chairman.

Evaluation of Wrapped Coatings for Underground Pipe Protection by H. W. Wahlquist, Ebasco Services, Inc.

New Developments in Holiday Detection by John P. Rasor, Tinker and Rasor.

Cathodic Protection of Coated Pipe Lines—A Survey of Recent Advances, L. P. Sudrabin, Electro Rust-Proofing Corp.

Bay Area Section Hears Seymour on Plastics Use

At the October 26 meeting of San Francisco Bay Area Section attended by approximately 65 members and guests, R. B. Seymour of Loven Chemical Company spoke on Plastics for Corrosion Resistant Applications. Dr. Seymour elaborated on his recently published book, a copy of which was presented to one of the members in attendance. Members of the Society of Plastic Engineers were present at the meeting as guests.

Central Arizona Section Tours Plant in Phoenix

Central Arizona Section's November 15 meeting was scheduled to consist of a tour of Deer-O Paints and Chemicals Limited in Phoenix, Arizona. Following a tour of the factory, an informal discussion was planned on the following subjects: Paint raw material and manufacture; Developing, testing and quality control of paint; Corrosion prevention by use of paint; Structural steel maintenance, pretreatment, priming, finishing; Interior painting, surface, priming, finishing; Government specification paints; Assembly line painting, flow coating, electrostatic spraying, roller coating and a general discussion.

Steel Transmission Tower Corrosion Is Topic

Corrosion of Steel Transmission Towers was the topic of a discussion by R. V. Moorman and R. Nyland of Bonneville Power Administration and William Wilson of Northwest Testing Laboratories before Portland Section September 22. There were 11 members and 13 guests present.

The discussion centered around an investigation into serious corrosion of Bonneville Power Administration transmission tower legs and failure of anchor rods.

Careful Engineering of Plastics Urged by Seymour

Careful engineering of plastics for industrial uses was urged by R. B. Seymour of Loven Chemical Company before a meeting of 10 members and 19 guests of Portland Section at the Campbell Court Hotel October 27. The use of plastics for corrosion resistant applications is growing at a rate faster than the rate of the rapidly growing plastics industry, Mr. Seymour said. He emphasized the need for rigid specifications in using plastics.

Officers were elected as follows: Norman H. Burnett, Huntington Rubber Mills, Portland, Ore., chairman; Robert S. Baynham, Dearborn Chemical Co., Lake Grove, Ore., vice-chairman, and William R. Barber, Jr., Electric Steel Foundry Co., Portland, secretary-treasurer.

East Tennessee Holds Four-Session Clinic On Equipment Design

"Equipment Design for Corrosion Prevention," was the theme of a four-session corrosion clinic held during the first two weeks of November by East Tennessee Section.

The four speakers and the subjects they discussed during the series were: October 31—J. M. Williamson, The Duriron Co., Chemical Pump Design, in Knoxville; November 3—A. L. Gray, The Pfaudler Co., in Oak Ridge, Glass-Lined Equipment for Chemical Service; November 7—E. P. Tait, Alloy Steel Products Co., in Knoxville, Valves for Corrosive Fluids and on November 10—J. L. McPherson, Blaw-Knox Co., in Oak Ridge, Design and Fabrication of Process Equipment.

Miller

E. C. Miller, Oak Ridge National Laboratory, spoke at the September 26 meeting of the section on Structural Materials for Nuclear Reactors. Dr. Francois Kertesz, Oak Ridge National Laboratory, was technical chairman for the session.

Mr. Miller, a metallurgist with considerable background in the application and use of metals in the atomic energy field, gave a review of the types of materials of potential use in nuclear reactors and the requirements of these different types both conventional and nuclear. He emphasized the use of aluminum, magnesium, iron, nickel, zirconium and their alloys.

He discussed problems presented in the use of standard and newly developed materials in reactor pressure vessels, including safety provisions, design, maintenance and radiation effects. He concluded his remarks with a discussion of some of the unusual demands, precautions and remedies necessitated by corrosive conditions encountered in reactor systems.

Final meeting of the section will feature a discussion by W. A. Luce of The Duriron Co. on the use of Duriron anodes for the mitigation of corrosion.

New Vinyl Developments Emphasized by Munger

New developments in the application and use of vinyl maintenance coatings were discussed by C. G. Munger, Amercoat Corp., South Gate, Cal. at a dinner meeting of Detroit Section November 10. There were 40 members and guests present. The meeting was held at the Engineering Society of Detroit.

Mr. Munger's discussion covered hot spray, vinyl mastics, and details of use and resistance of these coatings.

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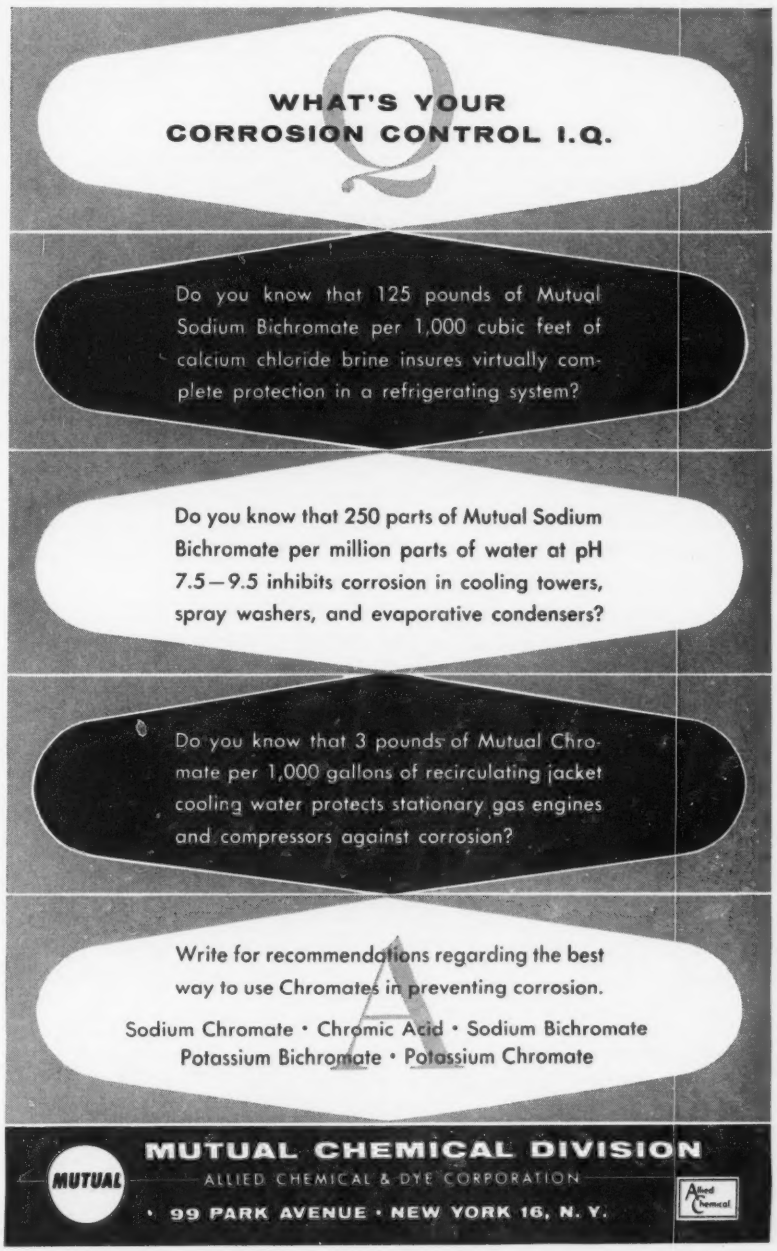
Oklahoma Short Course to Focus on Practical Aspects

Objective of the April 3-5 Corrosion Control Short Course to be given by the University of Oklahoma, Norman is to make engineers and operating foremen better acquainted with the practical aspects of corrosion control. The College of Engineering and the Extension Division of the university are holding the course in cooperation with the Central Oklahoma Section of the National Association of Corrosion Engineers. Richard V. James, Professor of Mechanics, Chairman of the School of General Engineering, will direct the course.

Special sections will be provided for consideration of corrosion problems in oil production, pipelines, public utilities, refineries and plants and instrumentation. The morning session April 3 will be devoted to economic evaluation of corrosion control program.

Registration fee for the course is $15 and a $2.50 charge will be made for a banquet April 4. Rooms for men are available at the Extension Study Center dormitories at $1.50 and $1.75 per person per night and family accommodations are available at nearby hotels and tourist courts. Breakfast, lunch and dinner will be available at moderate cost at the Extension Study Center cafeteria.

A complete schedule for the course will be distributed in March. Advance registrations may be sent to M. L. Powers, Director Business and Industrial Services, Extension Division, The University of Oklahoma, Norman, Okla.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Klim is 1956 Chairman Of Schenectady Section

Officers were elected as follows by Schenectady-Albany-Troy Section for 1956: J. F. Klim, New York Telephone Company, chairman; R. T. Foley, General Electric Company, vice-chairman; and H. A. Cataldi, General Electric Company, secretary-treasurer.

F. L. LaQue of International Nickel Company, Incorporated, spoke before approximately 30 members and guests at the section's November 1 meeting on "Some Apparent Anomalies of Corrosion."

The following programs were announced:

January 10 at Union College, featuring a series of brief talks by members on their particular corrosion interests.

February 7, R. C. Ulmer of Combustion Engineering, Incorporated, will speak on "General Corrosion Problems in Industrial and Marine Boiler Operation."

The April meeting will be a joint dinner meeting with the American Society of Electroplaters.

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PHILADELPHIA PANEL MEMBERS, left to right, Howard H. Bennett, Socony Mobil Oil Co., Paulsboro, N. J., moderator; Charles P. Dillon, Carbide and Carbon Chemicals Co., Texas City, Texas; Michael Monack, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.; Robert Pope, Ebasco Services, Inc., New York and C. R. Payne, Electro Chemical Engineering and Supply Co., Emmaus, Pa.

A. B. Bagsar

Aaron B. Bagsar, Chief Metallurgical Engineer, Sun Oil Co., Philadelphia died October 2. He retired about two years ago.

A member of NACE since 1945, he was a charter member of Philadelphia Section. He held a BS from University of California, Berkeley; MS from University of Idaho and PhD from Columbia University of New York. He had spent more than 20 years in corrosion work for his company.

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Philadelphia Section Holds Its Annual Round Table Session

Interesting facts on the preferred materials, coatings and fabrication techniques for corrosion prevention and a suggestion for protection of piping used for radiant heating of roadways were developed during a panel discussion at Philadelphia October 14. A four-man panel discussed questions submitted to it at the Philadelphia Section's annual fall round table discussion meeting. The program was preceded by a dinner and social hour.

Members of the panel were Robert Pope, Ebasco Services, N. Y., who discussed cathodic protection; Michael Monack, E. I. duPont de Nemours & Co., Inc., Wilmington, Del. who discussed protective coatings; Charles P. Dillon, Carbide and Carbon Chemicals Co., Texas City, Texas, who discussed metals and C. R. Payne, Electro Chemical Engineering and Supply Co., Emmaus, Pa., who discussed non-metallic materials. H. H. Bennett, Socony Mobil Oil Co., Paulsboro, N. J., past chairman of the section acted as moderator.

Some of the salient points developed were: Plastics—Asbestos, fiberglass and other fillers increase the strength of plastics provided they are themselves resistant to the environment. Stainless Steel—Type 329 is superior to Type 316 in resistance to pitting and cracking in brackish water.

Welding Stainless Steel—Use rods of the same or higher alloy. Abrasion-Resistant Coatings—Sprayed metal coatings may resist abrasion successfully up to 475 F. Radiant Heated Roadways—Impressed current with carbon anodes suggested for protection of piping systems used in radiant heating of roadways. Protection of Elevated Water Tanks—Coating the area covered by the fluctuating water line in water tanks was recommended in addition to cathodic protection. Hot mastic coatings usually are used.

The following were nominated for election to section offices: Thomas F. Degnan, E. I. du Pont de Nemours & Co., Inc., Penn's Grove, N. J., chairman; S. F. Spencer, Keystone Shipping Co., Philadelphia, vice-chairman and M. L. Rosenfeldt, Water Service Laboratories, Inc., Philadelphia.

Next meeting of the section is scheduled December 9.

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CERTIFICATES for PAST CHAIRMEN of REGIONS and SECTIONS

Certificates measuring 9 x 12 inches in size, prepared from an engraved plate, are available for issuance to regional and sectional chairmen. They will be supplied on request of the region or section at $7.50 each to be paid by the region or section, the cost to be classified as a non-reimbursable expenditure.

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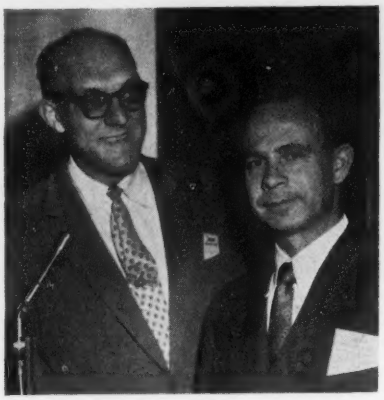


AT CHICAGO MEETING, V. M. Kalhauge, Standard Oil Co. (Ind.), master of ceremonies is shown with P. F. George, Dow Chemical Co.

Advantages of New Anodes Are Explained

Advantages of the new Dow Chemical Company, magnesium anode over older types were explained to 65 members and guests of Chicago Section at an October 18 meeting. P. F. George, of Dow, told of his company's 10-year investigation of anode types and alloys.

Mr. George said that among the advantages of the new anode were its ability to supply sufficient current for adequate protection in high resistivity soils and its reduced installation cost because fewer anodes are required on a given length of pipe for protection. His talk was illustrated with slides.

Host company at the Fellowship Hour was the Amercoat Corp., with H. J. Miller as senior host assisted by C. P. Molcar and P. E. Henneberry.

Corrosion and Design will be the topic of C. G. Munger, of the Amercoat Corporation at the November meeting.

NACE MEETINGS CALENDAR

Dec.

1 Pittsburgh Section. Mellon Institute.

5 North Texas Section. At Fort Worth. Instrumentation for Corrosion Measurements, Bethel Bond, Cathodic Protection Service.

6 Southwestern Ohio Section. Inspection trip, Cincinnati Milling Machine Co. auditorium, 2:30 pm. Dinner meeting, Shuller's Restaurant, Reading, Ohio.

7 Greater Boston Section. High temperature corrosion, Prof. Grant, Massachusetts Institute of Technology.

7 Metropolitan New York Section. Chemists Club, New York City.

8 Sabine-Neches Section. Panel discussion on refinery corrosion problems, Chris Murray, Pure Oil Co., Port Neches, Texas, moderator.

26 Tulsa Section. Christmas party.

Jan.

5 Pittsburgh Section. Mellon Institute Oakland, Pa.

9 Philadelphia Section.

9 North Texas Section. At Dallas. What's What in Plastics, W. M. Thornton, Atlantic Refining Co.

10 Schenectady-Albany-Troy Section. At Union College, featuring brief talks on corrosion interests by members.

17 Chicago Section. Corrosion measurements, C. H. Samans, Standard Oil Research Laboratories.

17 Cleveland Section. Joint meeting with The Electrochemical Society.

17 Genesee Valley Section. Electroless plating, tentative German Club.

19 Sabine-Neches Section. Copper Base Alloys, Al Wafer, Ohmstede Machine Works, Beaumont.

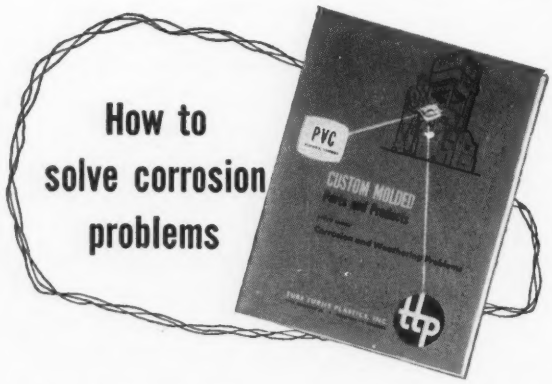
19 Kanawha Valley Section. At Huntington, W. Va. Corrosion Behavior of Aluminum Alloys in Different Environments, Wayne W. Binger, Aluminum Co. of America.

23 Tulsa Section. Protective coatings.

25 Metropolitan New York Section, Chemists Club.

31 Southwestern Ohio Section. Causes of Corrosion, Part 1, Sol M. Gleser, A. M. Kinney Co., Cincinnati. Shuller's Restaurant, Reading, Ohio.

Keep this copy of Corrosion for reference. It includes the index by topics and subjects of the 12 issues of Volume 11, 1955. Extra copies of this issue are available.



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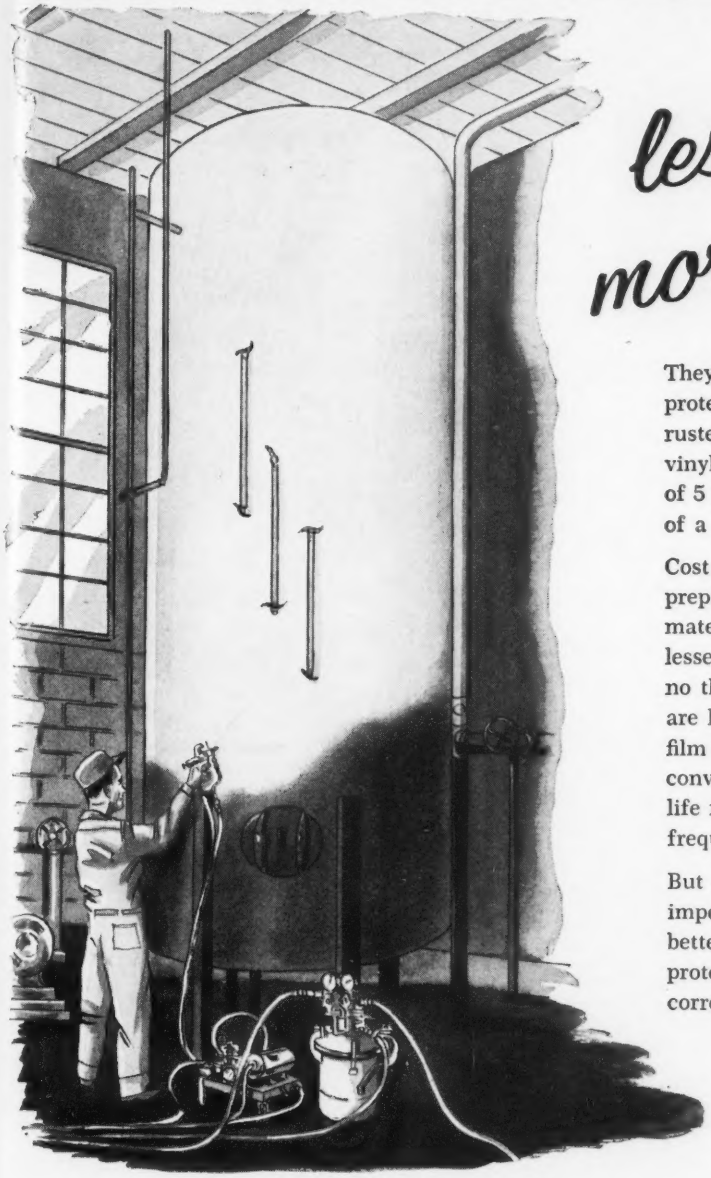

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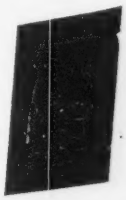

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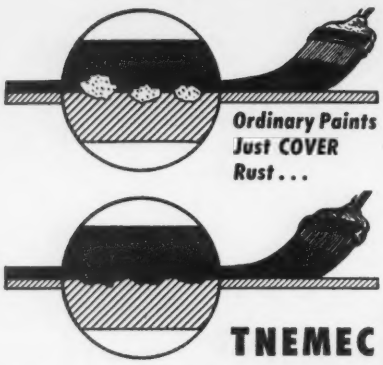

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Four Technical Papers from Foreign Sources Are Accepted for Presentation at New York

Program Co-Chairman Is Promoted by Shell Oil

R. T. Effinger, co-chairman of the Technical Program Committee for the March NACE Conference in New York, in July was made assistant chief engineer at the Shell Oil Company's Houston refinery, has been active in corrosion work since 1942. After receiving a BS in chemistry from University of Washington in 1938, he returned to Shell Oil's Martinez, Cal. refinery as a technologist. He previously had been employed by Shell in December 1935.

Effinger

In 1942 he was transferred to the engineering department at the Martinez refinery as a corrosion engineer, and afterward became chief inspector and a design and project engineer. In 1950 he was transferred to the manufacturing and engineering department of Shell at New York as a senior engineer responsible for material selection, corrosion prevention and standards.

Mr. and Mrs. Effinger have three children, one now in the air force and two attending high school. They have built a home in Houston.

Advance Registration Plans Made for New York

Registrations will be accepted in advance of the March 12-16 Twelfth Annual Conference of NACE at Hotel Statler, New York. Arrangements have been made to mail an advance registration form in January with the tentative program and hotel reservation card. The form will be returnable to Central Office NACE at Houston and will not call for advance payment of registration fees.

Envelopes will be prepared at NACE Central Office for those who register in advance, containing identification badge, official program, tickets and other material. This envelope will be issued at New York from a special advance registration desk and is expected to save considerable time for those who register in advance.

N. Texas Section Hears Talk on Wrought Iron

Approximately 35 members and guests attended the November 7 meeting of the North Texas Section. Evard P. Best, A. M. Byers Company, Pittsburgh, presented a paper on wrought iron. In addition to his talk, Mr. Best showed a motion picture entitled "Eternally Yours" and several slides showing various wrought iron installations.

Best

Four technical papers from foreign sources have been accepted for presentation during the March 12-16 NACE Conference in New York. At least two other papers are in the negotiation stage. W. Z. Friend, International Nickel Co., Inc., chairman of the technical program committee issued the following information about these papers:

Corrosion by Low-Pressure Geothermal Steam by T. Marshall and A. J. Jughill, Dominion Laboratory, Department of Scientific and Industrial Research, Wellington, New Zealand.

Cathodic Protection of Creole Petroleum's Lake Maracaibo Gathering System by R. L. Benedict, Creole Petroleum Corp., Cabimas, Venezuela, S. A.

Cathodic Protection of Ship Hulls, Large Farm Water Piping, Domestic Water Boilers, Deep Well Pumps and Concrete-Lined Prestressed Steel Water Conduits by D. Spector, Tel Aviv, Israel.

Concerning Napthenic Acid Corrosion by someone connected with N. V. de Bataafsche Petro Maatschappij, The Netherlands.

Two papers are in negotiation through the offices of the Inter Society Corrosion Committee from authors in Germany and Italy.

Titles given are not necessarily those which will apply to the final version of the papers.

Interesting Ladies Program Prepared by Mrs. Bailey

Mrs. B. J. Bailey, chairman of the Ladies Activities Committee for the Twelfth Annual Conference and Exhibition at New York promises she and her committee will keep lady visitors "entertained and happy and with a minimum of expense to husbands." Mrs. Bailey held the same job for the 1951 NACE Conference and many who attended that meeting will remember her successful work.

Plans so far completed for the ladies' program include: March 12, Welcome Brunch; March 13, evening, Fellowship Hour; March 14, morning, Radio City tour, broadcast and television; March 15, morning, United Nations tour and luncheon. Ladies' registration fee will cover these activities. A special luncheon and fashion show at Hotel Pierre on March 13 will be additional.

In February a "For Ladies Only" brochure will outline the complete program and list Broadway plays and television shows originating in New York for which tickets are available.

Southwestern Ohio Section Hears T. J. Maitland

Approximately 30 members and guests attending the October 25 meeting of Southwestern Ohio Section heard T. J. Maitland, American Telephone & Telegraph Company speak on the Scope of Corrosion Engineering. This was the first meeting of the section of the current season. The next regularly scheduled meeting was November 29, when M. G. Fontana, Ohio State University, Columbus, was scheduled to speak on Illustrations of Corrosion.

37 Firms Reserve Space in N.Y. Corrosion Show

Thirty-seven firms have reserved space in the Corrosion Show to be held concurrently with the Twelfth Annual Conference and Exhibition at New York March 12-16. The exhibition and all technical events on the 5-day program will be held in Hotel Statler.

Exhibitors who have not yet forwarded their reservations are urged to do so speedily. Any firm that is interested in the possibility of exhibiting during the New York conference is invited to write for descriptive brochure and contract forms to: A. B. Campbell, Executive Secretary, National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas.

Exhibitors so far are:

Amercoat Corporation, South Gate, Calif.; Bart Manufacturing Corp., Belleville 9, New Jersey; A. E. Betzel Engineering Company, Arlington, Texas; A. M. Byers Company, Pittsburgh; Cameron Iron Works, Incorporated, Houston; Philip Carey Manufacturing Company, Cincinnati; Centriline Corporation, New York, New York; Coast Paint and Lacquer Company, Inc., Houston; Crest Instrument Company, Seattle, Washington; The Dampney Company, Hyde Park, Boston; Dearborn Chemical Company, Chicago; Dresser Manufacturing Division of Dresser Industries, Inc., Bradford, Pennsylvania; Federated Metals Division of American Smelting & Refining Company, New York; General Ceramics Corporation, Keasby, New Jersey; The Glidden Company, Cleveland; Gulf States Asphalt Company, South Houston, Texas; Hill, Hubbell & Company, Division of General Paint Corporation, Cleveland; Johns-Manville Sales Corporation, New York; Robert J. Kerr Chemicals, Inc., Park Ridge, Illinois; F. H. Maloney Company, Houston; Metallizing Engineering Company, Inc., Westbury, L. I., New York; The Pfaudler Company, Rochester, New York; Chas. Pfizer & Company, Inc., Brooklyn, New York; Pittsburgh Coke & Chemical Company, Pittsburgh; Reilly Tar & Chemical Corporation, Granite City, Illinois; Rust-Oleum Corporation, Evanston, Illinois; Socony Paint Products Company, Metuchen, New Jersey; Tapecoat Company, Evanston, Illinois; Texsteam Corporation, Houston; Standard Magnesium Corporation, Tulsa, Oklahoma; D. E. Stearns, Shreveport, Louisiana; Stuart Steel Protection Corporation, Kenilworth, New Jersey; U. S. Stoneware Company, Akron, Ohio; Haynes Stellite Company & National Carbon Company, Divisions of Union Carbide & Carbon Corporation, New York; Valdura Division of American-Marietta Company, Chicago; Minnesota Mining & Manufacturing Company, St. Paul, Minnesota; Carboline Company, St. Louis, Missouri.

Looking Forward To January Issue:

Technical papers scheduled for publication in the January issue are:

- Correlation of the Results Obtained with Corrosion Inhibitors in the Laboratory and in the Field by G. E. Purdy and W. J. Ries.
- A Study of Protective Criteria on a Pipe Section in a Uniform Environment by L. P. Subrabin.
- Induced Alternating Current Used for Cathodic Protection of a Coated Pipe Line by S. J. Bellassai.
- Inhibition of Metallic Corrosion in Aqueous Media by H. C. Gatos.
- The Investigation of an Unusual Case of Shipbottom Pitting by R. P. Devoluy.
- Corrosion of Gasoline Engine Exhaust Valve Steels by C. H. Allen and Max J. Tauschek.
- Final Report on Four Annual Anode Inspections at Ground Beds Installed for Committee Test Program by Technical Unit Committee T-2B on Anodes for Impressed Current.
- Tentative Recommended Specifications and Practices for Coal Tar Coatings for Underground Use by Technical Unit Committee T-2G on Coal Tar Coatings for Underground Use.

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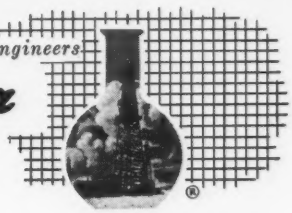

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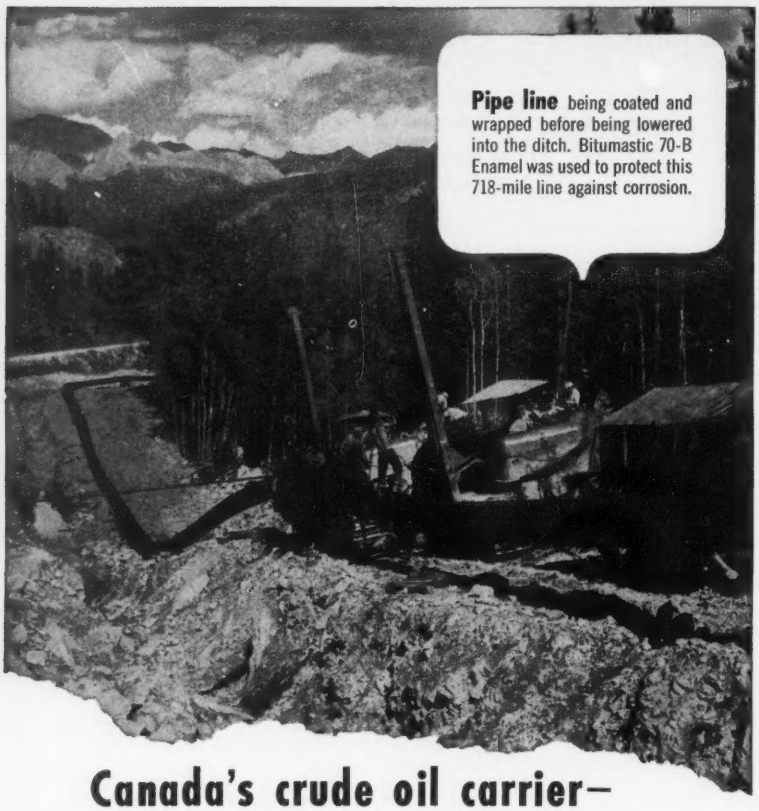

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54 Students Attend Houston Section Meeting

Houston Section's annual student night attracted 54 students and faculty members November 8 from colleges in the vicinity. Students came from Texas A & M, University of Houston, Rice Institute and Lamar College. A fellowship hour preceding dinner gave students and section members an opportunity to get acquainted.

Carl B. Kreiner, Gold Seal Company of Houston, principal speaker, discussed the relationship between engineering and production groups and the sales force. He emphasized the need to tell the engineer's story on corrosion control and to learn how advertising and sales promotion can contribute to technical and personal success. Mr. Kreiner, a graduate of the School of Commerce, University of Iowa, is past president of the Houston Sales Executives Club and director-at-large of the National Sales Executives Association.

A. E. Richey, Cathodic Protection Service chairman of Houston Section, introduced J. J. Calhoun, recently appointed Dean of Engineering at Texas A & M and chairmen of Houston Section committees responsible for the successful October South Central Region meeting.

Faculty members present were: Representing Lamar College, R. V. Andrews; representing University of Houston, Warren Anderson, T. E. Pfieffer, V. W. Salisbury, J. R. Sims, A. J. Chapman; representing A & M, J. D. Lindsay, W. D. Harris, Henry Rakoff, R. M. Galloway, W. W. Smith, H. T. Kennedy, Mike Rickoff.

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Houston Tappi Papers Cover Digester Corrosion

Internal Temperature Of Plates Investigated By Mexican Engineer

Factors involved in the corrosion of digesters were covered by two papers and a discussion session during the November 7-10 Tenth Engineering Conference of the Technical Association of the Pulp and Paper Industry at Houston. A discussion session on a new questionnaire "Corrosion Problems and their Economics," also was held under H. O. Teeple, The International Nickel Co. Inc., New York.

A. Tirado A., Fabrica de Celulosa, Tlalpan, D. F., Mexico, speaking on the subject "Experiences With Digester Corrosion in a Mexican Pulp Mill," told of some of the investigations his company is conducting into the reasons for corrosion of its digesters. After explaining how new digesters were erected, he related some of the work done to determine the principal reasons for their corrosion.

These investigations, Mr. Tirado said, indicate that the severity of corrosion is related to the capacity of the steel walls to dissipate heat and to dry distillation of acids from wood chips adjacent to hot walls. Any condition which keeps the chips from cooling contributes to corrosion, he said.

Measure Heat in Plates

Temperatures were recorded in the interior of digester walls at distances of 7/8 and 7/32 inch. These records indicate that in some charging cycles there may be a differential in temperature at the two depths of from 8 to 14 C. This, Mr. Tirado said, probably was sufficient to detach protective scale.

Design of Digesters Important

"Design Features Affecting Digester Corrosion," a summary of a round table discussion of the Tappi Corrosion Committee held at the 40th Annual Meeting of Tappi in New York, February 20, 1955, was presented by L. G. Pfeiffer. The summary was compiled by Mr. Pfeiffer, M. A. Schiel and E. H. Schmidt, all of A. O. Smith Corp., Milwaukee, Wis.

This summary considered the effects of different kinds of circulating systems, the advantages of the skirt over pedestal supports for digesters, proper design of internal projections, surface preparation of carbon and alloy steel used in digesters and stress relief and radiography. Mr. Pfeiffer brought out the fact that it is necessary to remove the calcium sulfate scale from stainless steel liners if pitting and stress corrosion cracking are to be avoided. Effect of sandblasting and other means of surface preparation are considered. Removal of mill scale is recommended.

Some of the results of failing to properly stress relieve welded areas are considered and some consideration is given to local stress relieving on repaired sections and to shot peening as a means of doubtful effectiveness to reduce stresses near welds.

ASME Meeting Includes Papers on Corrosion Topics

Cavitation, high temperature corrosion, corrosion and deposits from combustion gases and combating corrosion with glass coating were subjects for discussion at the "Diamond Jubilee Meeting" of the 40,000-member American Society of Mechanical Engineers in Chicago Nov. 13-18.

A paper titled "Cavitation" was given as part of the symposium on hydraulics. "Stress Corrosion Cracking of Type 347 Stainless Steel by Treated Boiler Water" was the subject at a meeting on boiler feedwater studies.

"High Temperature Corrosion of Alloys Exposed in the Superheater of an Oil Fired Boiler" was discussed Monday evening in a symposium on "High Temperature Steam Generation—Power." At a symposium on cavitation in pumping machinery three papers were given: Thermodynamic Aspects of Cavitation in Centrifugal Pumps, Turbulence and Boundary Layer Effects on Cavitation Inception from Gas Nuclei, and Critical Considerations on Cavitation Limits of Centrifugal and Axial-Flow Pumps.

Fouling and corrosion of a boiler in an electric power generating station were discussed in a symposium on "Furnace Performance Factors—Corrosion and Deposits from Combustion Gases—Power."

Combating Corrosion with a Glass Coating was discussed in a metal processing symposium.

AISI Report Surveys Stainless Curtain Walls

Metal curtain walls for buildings is the subject of a 190-page report by Princeton University's School of Architecture published recently. The project was on behalf of the Committee of Stainless Steel Producers, American Iron and Steel Institute. Because of the advantages of high strength and low weight, metal curtain walls are being used extensively in large building construction.

The report indicates that with stainless steel, the corrosion and maintenance problem is reduced to a minimum. Saving on available area because of thinner walls amounts to $36,000 a year in a building 100′ x 200′, 20 stories high with a rent of $6 per square foot, the report pointed out. Another advantage is speed and ease of construction. The walls are installed from inside the building, eliminating the need for scaffolding.

New Hypothesis Advanced On Hydrogen Embrittlement

Hydrogen enters into metals during pickling or plating through formation of solid solutions or metal hydrides according to an hypothesis detailed in a technical paper given at the annual fall meeting of the Electrochemical Society in Pittsburgh by L. D. McGraw, Battelle Memorial Institute, Columbus, Ohio.

Mr. McGraw held solid solution or metal hydride formation to be a more likely mechanism of hydrogen entry than the adsorption of atomic hydrogen or the formation of molecular hydrogen in the metal. The mechanism proposed by McGraw does not require that entry occur at specific rifts or lattice defects in metals. Entry may be at any point.

Hydrogen accumulation in metals during plating or pickling processes depends on the combination of rates of entry, diffusion and exit of hydrogen. These vary with conditions in the bath. If oxidizing agents are present, hydrogen exit is speeded and less embrittlement occurs. Impurities such as chlorinated hydrocarbons and arsenic will reduce the exit rate, resulting in more embrittlement, he said.

James T. MacKenzie Gets Southern Chemist Award

James T. Mackenzie, American Cast Iron Pipe Co., Birmingham, Ala. was given the 1955 Southern Chemist Award November 4. The presentation was made at a Southeast Regional Meeting of American Chemical Society sections at Columbia, S. C., in recognition of his important researches and writings in metallurgical chemistry and in appreciation of his years of service in the offices and committees of his profession.

Mr. Mackenzie, a graduate of University of the South, Sewanee, Tenn. has received many other honors including the 1951 ACS Herty Medal. He also has been active in the American Society for Metals and has been a member of the National Association of Corrosion Engineers since 1944.

Tests on Winterized Crane Continued in Alaska

Tests on a winterized crane at the Mesabi iron range in Northern Minnesota have been completed by U. S. Army Engineers. The crane, truck mounted, was lubricated with greases, equipped with flexible materials useful to —65 F and otherwise prepared for Arctic duty. The machine operated in sub-zero temperatures for two months. After minor modifications the crane was shipped to Big Delta, Alaska for further testing.

New Instruments Help Check Air Pollution

New instruments developed through the activities of the Air Pollution Foundation, Los Angeles have made it possible to keep closer check on concentration of atmospheric pollutants. Simultaneous recording of concentration of oxidants, oxident precursors, nitric oxide and nitrogen dioxide in a single instrument have simplified the efforts to control and predict smog, the foundation reports.

The foundation hopes to be able with this device and others to predict with some accuracy the occurrence of smog, or to indicate in advance when concentrations of pollutants make smog likely. This is possible because it seems proved that sunlight is the source of energy that converts otherwise harmless pollutants into choking gases.

Ozone Radiometer Developed

The ozone radiometer was developed to continuously record the volume of ozone in the air. This device is expected to yield important information because ozone is about 100 times as poisonous as carbon monoxide.

The foundation also is seeking to determine what percentage of the pollutants is emitted by busses, trucks and automobiles and what by other combustion systems. Hydrocarbon content of the air also is carefully sampled on an around-the-clock basis.

Another instrument has been developed by University of California at Berkelev scientists to count and segregate into 20 size groups particulate matter found in the atmosphere. It is anticipated that chemical analyses of these particles will be helpful in reaching a solution of the smog problem. Balloon-supported aero-meteorographs to record continuous readings of temperature, air pressure and relative humidity will be sent aloft to gain more information about the inversion layer believed to be a principal reason for the concentration of smog-producing irritants in the air above Los Angeles.

Other Controls Started

An automatic gas cut-off device that stops the flow of gasoline into carburetors when deceleration draws unburned hydrocarbons through the engine and out the exhaust has been developed by the Chrysler Corporation and may be used by other automobile manufacturers. As much as 50 per cent less unburned hydrocarban vapors is expected from the use of this device.

Other measures adopted include special double hoses providing for return of hydrocarbon vapors to tanks in service stations being filled from trucks, purchase of dumps for burial of refuse instead of incineration by political subdivisions, banning of operation of domestic refuse burners.

Report on Houdry Smog Mufflers Is Published

Report No. 8 of the Air Pollution Foundation, 704 Spring Street, Los Angeles 14, Cal., gives details of the testing of three types of Houdry catalytic exhaust gas smog eliminators. The catalyst mufflers were designed for use on passenger automobiles. Tests revealed only one of three types tested was sufficiently efficient to merit use but it was believed of doubtful value because it required exclusive burning of unleaded gasoline.

High Capacity Silicon Rectifiers Are Developed

Silicon rectifiers capable of handling up to several kilowatts of power have been developed by Westinghouse Corp. New diodes have a typical forward voltage drop of only 0.7 volts at a current of 8 amperes and at a cell temperature of 190 degrees Centigrade. This was reported in Industrial Research Newsletter published by Armour Research Foundation of Illinois Institute of Technology, Chicago.

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LSU Corrosion Seminar Sessions Begin Sept. 30

A seminar on corrosion was held on nine days beginning September 30 at Louisiana State University, Baton Rouge. The course, consisting of 18 three-hour sessions was organized by Arthur G. Keller, Professor of chemical engineering.

Subjects and the speakers covering them were as follows: corrosion theory, Norman Hackerman, University of Texas; Louis Sline, Sline Industrial Painters, Houston, surface preparation and protective coatings; R. D. Williams, Celanese Corp. Charlotte, N. C., corrosion theory; Scott Ewing, Carter Oil Co., Tulsa, Okla., cathodic protection and corrosion by soils; W. Z. Friend, The International Nickel Co., Inc., New York, N. Y., protection against corrosion; R. B. Seymour, Loven Chemical of California, Newhall, Cal., plastics for corrosion resistance; T. P. May, The International Nickel Co., Inc., marine corrosion testing; F. W. Fink, Battelle Memorial Institute, Columbus, Ohio, corrosion testing techniques.

All lecturers are members of the National Association of Corrosion Engineers.

Appointments Are Made in NBS Cryogenic Division

Four appointments in the Cryogenic Engineering Division of the National Bureau of Standards Boulder laboratories were made recently. B. W. Birmingham was appointed chief of the cryogenic equipment section and assistant chief of the cryogenic engineering division. He will conduct research on storage, transportation and apparatus for transfer of liquefied gases.

Peter C. Vander Arend has been appointed chief of the cryogenic processes section which studies low-temperature distillation as a means of separating isotopes, processes for purifying and liquefying gases and methods for production and analysis of liquid para-hydrogen.

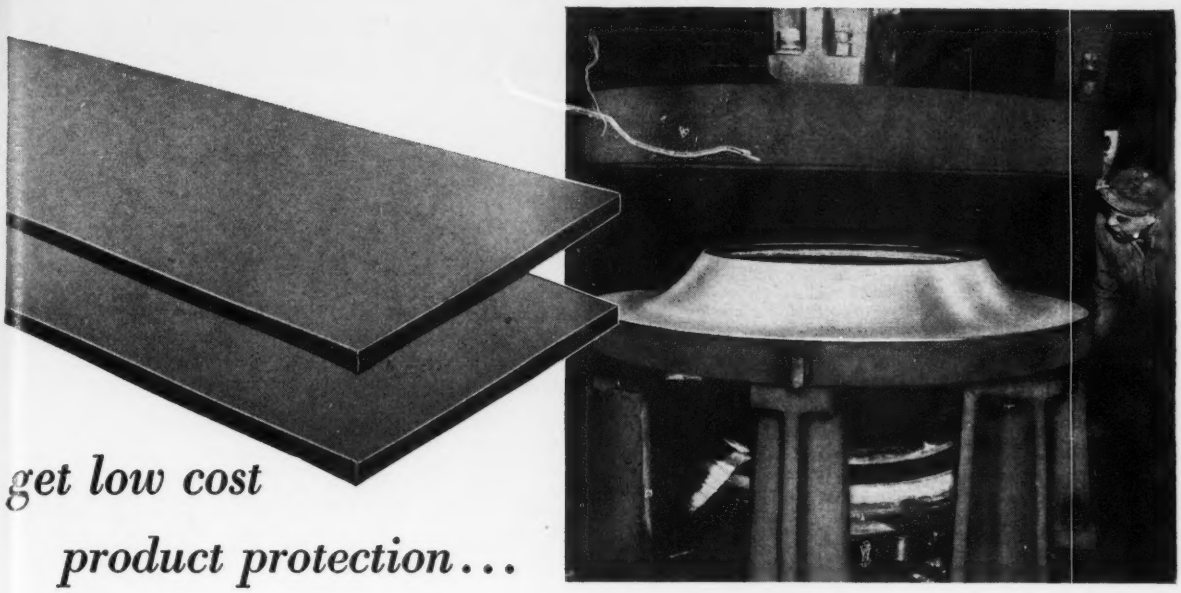
R. J. Corruccini is the new chief of the properties of materials section and will study the physical properties of materials at low temperatures.

V. J. Johnson has been appointed chief of the gas liquefaction section. This section is responsible for operation of liquefaction plants, producing liquid nitrogen, liquid hydrogen and liquid helium for research and for use of other government agencies.

Extension of Steam Tables To 1500 F Contemplated

Extension of present steam tables to 1500 F and 15,000 psi is contemplated under a research program sponsored by the Research Committee on the Properties of Steam of the American Society of Mechanical Engineers. James W. Parker, consulting engineer of Ann Arbor, Mich., chairman of the committee, reports progress is being made in fund raising but that additional contributions are solicited.

The International Skeleton Steam Table of 1934 stopped at 1032 F and 5000 psi.



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AWS Honors Four for Outstanding Achievements

Four men were honored for outstanding achievements in the field of welding at the fall meeting of the American Welding Society in Philadelphia, Oct. 17. La Motte Grover, Air Reduction Sales Co., delivered the Adams Honor Lecture. The lectureship honors an individual who has made a new or distinctive development in welding.

John J. Chyle, A. O. Smith Corp., received the Samuel Wyle Miller Medal for contributing conspicuously to the advancement of welding. Nikolajs Bredzs, Armour Research Foundation, was awarded the Lincoln Gold Medal for the paper judged as the most original contribution to the advancement and use of welding published in "The Welding Journal" during the year. William Spraragen, director of the Welding Research Council was presented an honorary membership in the American Welding Society for good service to the society. A student award was given to Monroe Edwards, Georgia Institute of Technology.

ASA Gold Medals Given To Two at Washington

Two gold medal awards given by the American Standards Association were planned for the Sixth National Conference on Standards at the Sheraton-Park Hotel, Washington, D. C., Oct. 24-26.

Harold S. Osborne, Montclair, N. J., was selected to receive the Howard Coonley Medal for "service in advancing the national economy through voluntary standards."

James G. Morrow, Steel Company of Canada, Ltd., Hamilton, Ontario was designated to receive the Standards Medal, awarded annually for leadership in the development and application of voluntary standards. The American Standards Association is the national clearinghouse for voluntary, industrial and consumer standards.

NBS Mathematician to Work on Random Numbers

Dr. Emilie V. Haynsworth has become a member of the National Bureau of Standards, specializing in mathematics. One phase of her work will be in application of random numbers. This is the system used to sort and select desired cards in the National Association of Corrosion Engineers punched abstract card system.

In another appointment, Dr. Samuel Zerfoss was made chief of the Refractories Section. He will study refractories used for protective coatings in high temperature use in both industrial and military applications.

Single Copy Price of 1952 Corrosion Goes Up January 1

The single copy price of Corrosion for the year 1952 will be increased to $2 to everyone, effective on January 1. On that date single copies of Corrosion for the years 1945-52 will cost $2, postpaid. The usual additional 65c additional book post registration fee applies to all shipments addressed to persons outside the United States, Canada and Mexico.

Three 1956 Meetings Interest ASA Members

Three meetings of interest to American Standards Association members have been set for 1956. The International Electrotechnical Commission will hold its annual 1956 meeting, June 27-July 6 in Munich, Germany. Delegates will be guests of the German National Committee of IEC.

A meeting of the council of International Organization for Standardization is scheduled for July 16-21 in Geneva, Switzerland.

The Seventh National Conference on Standards, sponsored by the American Standards Association in conjunction with its 38th Annual Meeting, Oct. 22, 23, 24 will be held at the Hotel Roosevelt, New York, New York. Address of the American Standards Association is 70 E. 45th St., New York 17, N. Y.

FPVPC Top Officials Are Elected at New York

Top officers of the Federation of Paint and Varnish Production Clubs were elected at the Federations 33rd annual meeting in New York, October 5.

Clyde L. Smith, president of Vi-Cly Industries, Inc., Compton, Cal. was elected president; Milton A. Glaser, vice-president of Midland Industrial Finishes, Waukegan, Ill., was elected president-elect and Howard G. Sholl, technical director of the C. M. Athey Paint Co., Baltimore, Md. was elected treasurer. Membership in the organization is about 3500.

Interior Department Water Report Considers Corrosion

Corrosion, one of many factors to be considered in use of water for paper making is covered in a report titled: Water Requirements of the Pulp and Paper Industry by O. D. Mussey of the Geological Survey, U. S. Dept. of the Interior. The report was prepared after consultation with the Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, the Department of Commerce. Purpose of the report is to provide information for defense planning and to render a service to business and industry in their attempts to conserve water.

AIChE Papers Related to Corrosion Are Scheduled

At least two papers of collateral interest to corrosion workers were scheduled during the American Institute of Chemical Engineers' annual meeting at Detroit November 27-30. They were: Mass Transfer in Liquid Metal Systems by W. E. Dunn, E. I. duPont de Nemours & Co., Ltd., Wilmington; C. F. Bonilla, Columbia University, New York; C. Ferstenberg, Du Pont, Philadelphia and B, Gross, Dugway Proving Grounds, Dugway, Utah and A New Technique for Drop-Size Distribution Determinations by A. P. Roy Choudhury and W. F. Stevens, Northwestern Technological Institute, Evanston, Ill.

•

An index to the Technical Committee Activities Section in Corrosion is published annually in December.

BOOK REVIEWS

Product Design, Handbook Issue for 1956. 8⅛ by 11¼ inches, 786 pages, heavy flexible paper cover. 1955. **Product Engineering,** McGraw-Hill Publishing Co., Inc., McGraw-Hill Bldg., 330 W. 42nd St., New York 36, N. Y. Per copy, Continental U. S. $1.00, elsewhere, $4.00.

Material for the Product Design Handbook was gathered from several different publications and technical society and association papers. Corrosion is considered only incidentally in the book.

There are chapters on general engineering, metals and alloys, non-metallic materials and finishes, fabrication and production processes, power transmission, mechanical parts and design analysis, fastening and joining, motors, engines and controls, electrical and electronic components and hydraulic and pneumatic equipment.

Stainless Steel Guide Issued

A general guide in the selection of stainless steels has been prepared by the American Iron and Steel Institute. Covering all standard types of stainless steels, the data sheet provides selected information on chemical composition, structure and general characteristics. Stainless steels have been classified by the American Iron and Steel Institute through use of numbers. The AISI system provides a single specification number recognized by all producers.

API Committees Meet

The Division of Refining and the Division of Transportation of the 35th Annual Meeting of the American Petroleum Institute held subcommittee meetings on corrosion November 13-14 in San Francisco at the Fairmont hotel.

The Subcommittee on External Corrosion has D. C. Glass as its chairman. Chairman of the subcommitee on Internal Corrosion of Crude-Oil Pipe Lines and Tanks is R. A. Brannon.

British Radiology Society Has Over 200 Members

The Society of Industrial Radiology and Allied Methods of Non-Destructive Testing, a British group organized for exchange of scientific information, has been in existence one year and has more than 200 members. D. N. Laurie, 2, Tomswood Terrace, Barkingside, Essex, is secretary.

W. J. Barrett Is Elected

Walter J. Barrett, treasurer of the American Institute of Engineers has been elected president of the United Engineering Trustees, Inc., the corporation which operates the Engineering Societies Library at 29 West 39th St., New York City.

Instrument Society to Meet

The Instrument Society of America will hold its 11th Annual Instrument-Automation Conference and Exhibit (International) in the new Coliseum building in New York City, Sept. 17-21, 1956.

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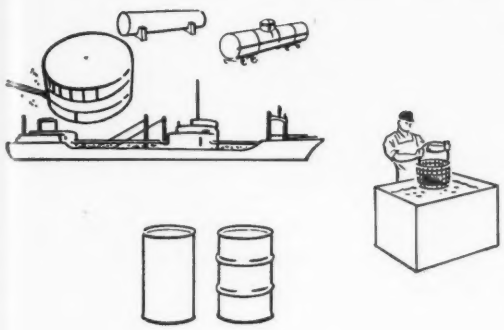

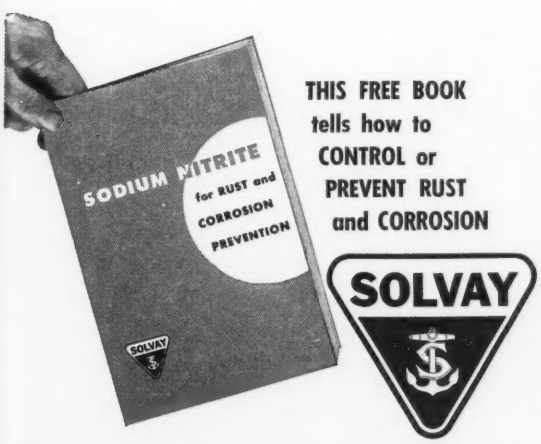

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Carbon Tetrachloride

NEW PRODUCTS —Materials—Service—Literature

Modern Filtration, a 16-page catalog of sintered bronze filters is available from Permanent Filter Corp., 1800 West Washington Blvd., Los Angeles, Cal.

•

Poly-Ep Platon, a two-component finish that can be applied to clean metal surfaces without prime coat is being produced by Minnesota Platon Corp., Pipestone, Minn. The coating dries dust free in 30 minutes at ambient temperatures. It is said to exceed federal paint specifications TTE 487B Olive Drab Rust Inhibitive Enamel requirements by 200 to 400 percent.

•

Volatile Inhibitor impregnated paper's uses in industry are briefly described in a folder available from Cromwell Paper Co., 4801 South Whipple St., Chicago 32, Ill.

•

Sunform, a polyester impregnated fiberglass material developed by the Electro-Technical Products Div., Sun Chemical Corp., Long Island City, N. Y., is made with random or woven fibers. Dr. Arthur L. Davis, is general manager of the division.

•

The Graham Laboratory for Jones and Laughlin Research, a $1,500,000 establishment, was dedicated October 28 at Pittsburgh.

•

The $8,500,000 main building of the U. S. Naval Radiological Defense Laboratory was dedicated October 14 at San Francisco.

•

Chemalloy Corp. is now located at 450 Tarrytown Road, White Plains, N. Y.

•

Berylco Product Directory, a 20-page illustrated brochure, describes in some detail the characteristics and availability of various beryllium alloys. Copies are available from The Beryllium Corp., Reading, Pa.

•

Portable Concrete Gunning rig with a capacity from 2 to 8 cubic yards an hour is available from Air Placement Equipment Co., 1009 West 24th St., Kansas City, Mo.

•

Hagan Corp. has issued Bulletin GSP-901 which describes the products and services of the Hagan companies. The 8½ x 11 inch, 24 page and cover illustrated bulletin is punched for catalog binders. It describes in detail ring balance instruments, components for control systems, measuring devices, testing equipment, feeding equipment, water conditioning and numerous other activities of the companies. Copies are available from the Hagan Corp., 323 Fourth Ave., Pittsburgh 30, Pa.

•

Epon curing agent T, a low viscosity, high boiling liquid, is a new curing agent developed for use with Epon resins by Shell Chemical Corp., 50 West 50th St., New York 20, N. Y.

•

Tube Kote, Inc., P. O. Box 20037, Houston 25, Texas has available for interested persons a technical data sheet on TK-31, a modified epoxy coating for use against corrosives in chemical and marine environments. The company announces also a custom coating service for valves, pipes and pressure vessels and a 4-page illustrated folder on its TK-2 plastic linings. These linings are recommended for protection against corrosion and paraffin deposition. Reaction of the coating with 17 corrosives and solvents is listed.

•

Climax Molybdenum has reprinted a comprehensive review of industrial applications of molybdenum chemicals which was originally published by the American Chemical Society. While 90 percent of molybdenum production goes into the making of metals, molybdenum has other important uses. Papers on molybdenum and its compounds used as catalysts, inorganic pigments, organic pigments, metal coatings, alloys for the chemical process industries and in agriculture may be obtained either singly or in combination by writing to Climax Molybdenum Co., Dept. L, 500 Fifth Ave., New York 36, N. Y.

•

Corrosion Services Incorporated, Box 7343, Tulsa, Okla., have printed a free report on the influence of size and shape of magnesium anodes on the cost of this type of protection. Anode life in soils of varying resistivity is given plus the cost of the anodes installed. The firm is a distributor of Dow magnesium anodes.

•

Minnesota Mining and Manufacturing Co., 900 Fauquier Ave., St. Paul 6, Minn., has published a 20-page reference manual on the uses and costs of "Scotchply" reinforced plastic. Principal features of the material are its ease of handling, high strength and uniformity. It is said to be essentially shatterproof, rotproof, mildewproof and water proof.

•

J. Walter Thompson Co., with offices in New York, Chicago, San Francisco, and Detroit, has printed information on the use of prefabricated aluminum houses to relieve a rural housing shortage in Colombia. The "Kingstrand" house is strong, does not harbor vermin or fungus, will not corrode and reflects the sun's heat, it is said. The houses can be shipped on the backs of mules or in airplanes in cartons 4 by 12 feet by six inches. Four unskilled workers can erect a house in 24 hours.

•

Plicoflex, Inc., 1566 E. Slauson Ave., Los Angeles 11, Cal., will provide free to those who request it on company letterhead, a Tape-Coating Data File giving complete information on Phicoflex polyvinyl chloride tape coatings for pipe line corrosion protection. Prices and technical data on single film and laminated tape coatings are listed.

•

Permacel Tape Corp., New Brunswick, N. J. has developed a new type pressure sensitive tape, said to be superior to ordinary friction tapes. One of the many uses listed for the tape is taping apertures in drums and tanks to keep out dust and moisture.

•

O. F. Zurn Co., 2736 N. Broad St., Philadelphia 32, Pa. has been appointed distributor for the Amercoat Corp., South Gate, Calif., manufacturers of corrosion preventive coatings. The firm also offers a consulting service on contamination problems.

•

Pennsylvania Salt Mfg. Co., 3 Penn Center Plaza, Philadelphia 2, Pa., has started construction on a plant to produce potassium hydroxide at its Calvert City, Ky. works. Much of the production of the plant will go to the soap, textile, chemical, pharmaceutical and petroleum industries.

•

Bart-Messing Corp., Belleville, N. J., has published a four-page booklet describing Sel-Rex Double Duty Filters for use in electroplating, chemical processing, pharmaceuticals, food and beverages, paints and varnishes, petroleum processing and other uses.

•

"Facts About Titanium," a small folder published by **Arthur D. Little, Inc.,** 30 Memorial Dr., Cambridge 42, Mass., contains a list of the commonly available titanium alloys and their compositions, forming and welding methods, heat treatment and machining information and current and projected prices. A brief comparison of titanium properties with those of a stainless steel and aluminum alloy is also included.

•

Safe-T-Spray Coatings, a recently perfected dry-mist paint is manufactured by **Phelan-Faust Paint Mfg. Co.,** 932 Loughborough Ave., St. Louis 11, Mo. The quick drying alkyd type paint is said to dry enough to wipe or brush from any object 30 to 40 feet from the spray gun—70 to 100 feet in cooler weather. It will adhere to metal, wood, concrete and old paint.

•

Superchrome Engineering Co., Los Angeles, Calif., specializing in hard chromium applications on rod and tubing for the oil drilling industry has what is said to be the deepest hard chromium plating tank in the U. S. The 45-foot tank is set in a pit 43 feet deep.

•

Ebasco Services Incorporated, New York, N. Y., has added a nuclear engineering division to its engineering department. F. C. Gardner, president of the firm said the company is prepared to render services on all phases of atomic energy applications to utility companies, industrial concerns, business enterprises and financial institutions. The division has been in preparation for 5 years.

•

Impervite, impervious graphite pipe and fittings can now be armored by a special process which uses strong, shock absorbing fiberglass cloth, impregnated with a chemical and heat resistant thermosetting plastic resin. The pipe is recommended for handling corrosive fluids. Additional information is available from John Reys, chief engineer, Falls Industries, Inc., Aurora Rd., Solon, Ohio.

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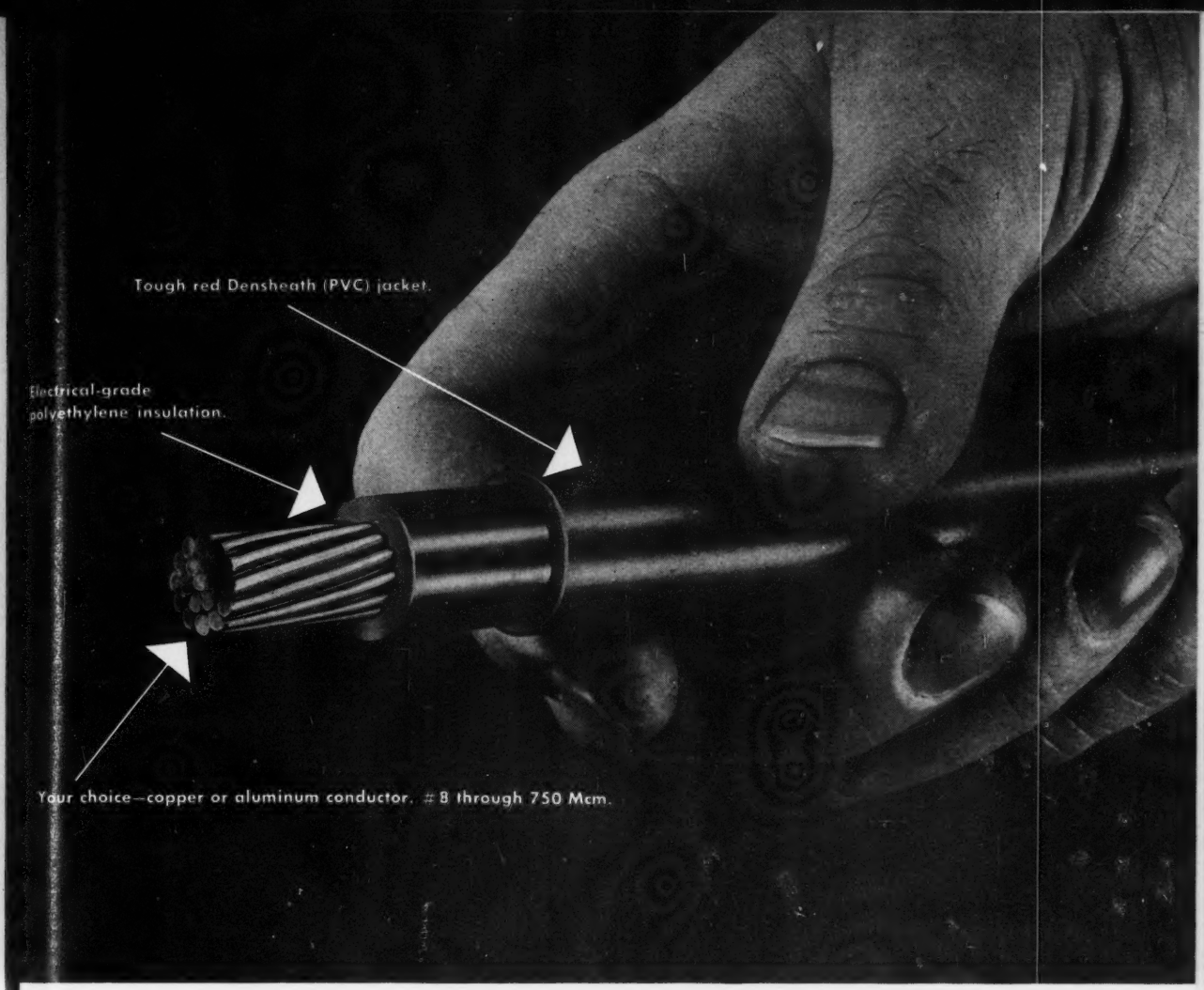
Mallory-Sharon Titanium Corp., Niles, Ohio, certifies the mechanical properties of the unalloyed titanium sheets manu-

(Continued On Page 94)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Cathodic Protection demands a special cable of its own. Anaconda's *Type CP Cable* offers top resistance to oil, soil acids, and electro-endosmosis . . . means *longer cable life.*

A pencil pokes through this corroded metal! Why chance trouble like this? Cathodic Protection and Anaconda Type CP Cable effectively check corrosion of buried metals.

Ordinary rubber cables – good as they are for the jobs for which they were *intended*–just can't give best service under the special conditions of cathodic protection.

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But now Anaconda offers a special Type CP Cable–that *lasts far longer* than ordinary cable in cathodic-protection systems.

High-grade polyethylene insulation and tough Densheath* (PVC) jacket offer amazingly high resistance to electro-endosmosis, as well as high resistance to oil, moisture, and most acids, alkalies and chemicals found in corrosive soil areas. And rugged Densheath withstands toughest abrasion, moisture and weathering.

To order, or for more information–call the Man from Anaconda. Or write: Anaconda Wire & Cable Company, 25 Broadway, New York 4, New York. 55342

*Reg. U.S. Pat. Off.

‡*Insulation failure when subject to d-c potential in wet locations.*

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NEW PRODUCTS

(Continued From Page 92)

factured by the firm. Certification is made possible by close quality control using statistical methods. Each heat of material is accompanied by a test report certifying an average strength level and also narrow limits of variability. In the past there has been wide variation in the mechanical properties of titanium sheets which has created serious problems in fabrication.

•

Industrial Tectonics, Inc. has purchased the manufacturing facilities of Anti-Friction Bearings Co., 5010 E. Washington Blvd., Los Angeles, Cal. In addition to bearings manufactured there for high temperature operation and other special requirements, the plant carries a stock of standard-size balls of special materials designed for corrosive and abrasive service, and sets of super-precision master balls for tool room and production gauging.

•

Sun Oil Company, 1608 Walnut St., Philadelphia 3, Pa. is producer of "Sunkote A," a new anti-rust coating oil which, according to the company, provides improved low-cost protection against corrosion of sheet and strip steel and ferrous castings. The product is described in Technical Bulletin 42.

•

Bakelite Co., division of **Union Carbide and Carbon Corp.,** producers of Bakelite fluorothene states it has other uses besides resistance to acids, alkalies, solvents and most chemicals. Linde Air Products has selected the material to make the water jacket adaptor on its 300-ampere welding torch. Reflected radiation from the powerful arc of the torch raises surface temperature as high as 400 F. Torch handles made of fluorothene do not warp or distort at this temperature.

•

Rogers Corp., Rogers, Conn. has announced the development of a reinforced Teflon sheet material offering substantially reduced cold flow and extrusion characteristics. The new material called Duroid 5600 is essentially Teflon into which inert fibers have been incorporated by a novel process that maintains the fiber structure.

•

Texas Alloy Products Co., 1403 N. Post Oak Rd., Houston, Tex. has published a surface Treatments Manual and Repair Replace Service brochure. The manual was written to aid in selecting metal surface treatments for metal parts to resist wear, heat and corrosion. The company's Repair Replace Manufacture service is described also.

•

Graver Water Conditioning Co., 216 W. 14th St., New York, N. Y. in conjunction with several plants in the nation has developed a new and effective method of combatting certain backwash difficulties occurring in filtration and ion exchange materials. The firm says the innovation, a sub-surface washer is being used with great success in demineralizers, zeolite softeners and filters experiencing excess fouling of beds.

•

Magnaflux Corporation, 7300 W. Lawrence Ave., Chicago 31, Ill. has published an 8-page brochure titled "Lower Manufacturing Costs." The book discusses savings made by continuous, overall inspection systems. One example of savings the book points out is the rejecting of raw materials and unfinished parts before processing time and money have been wasted on them. One of the products of the firm is Spotcheck, a dye penetrant inspection fluid in 12-ounce pressurized cans.

•

Palo Laboratory Supplies, Inc., 81 Reade St., New York 7, N. Y., makers of polyethylene laboratory ware describe and picture their products in a 12-page publication, Catalog D-1055. Their "new" polyethylene is "quite rigid, has much higher tensile strength and a softening point above 250 F," the company states.

•

Hagan Corp., in conjunction with **Calgon, Inc.,** a subsidiary, has developed a line of water softeners for manufacturing plants, institutions, and commercial establishments. The water softeners are package units so that only simple connections requiring a minimum of installation time are needed to fit a unit into a water system.

•

Hypalon, chlorosulfonated polyethylene, a synthetic rubber developed by E. I. du Pont de Nemours and Company, Inc., Wilmington, Del. is a new product which, the company states, has as its outstanding characteristics, color stability and resistance to heat, chemicals, oxidizing agents and weather. It is said to be particularly suited for chemical tank linings, hose, belting and protective coatings.

(Continued on Page 96)

Is Corrosion "*Eating Up*" Your Well Casing?

Cathodic protection, long used to protect steel tanks, pipe lines, piers and even ship hulls from galvanic corrosion, has now been successfully applied for external protection of oil well casings. CSI can offer you the following:

Expert consulting and installation services.

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- ✓ **Equipment to handle the largest turnkey job—rectifier or anode**

Brand-name materials and equipment—for either anode or rectifier installations.

- ✓ **Dow magnesium anodes, including the new Galvomag**
- ✓ **Special anodes to your own specifications**
- ✓ **Galvo-Paks—Vibration-packaged—silver-soldered lead wires, patented quick-wetting backfill**
- ✓ **Large stocks for immediate shipment**

Competitive prices.

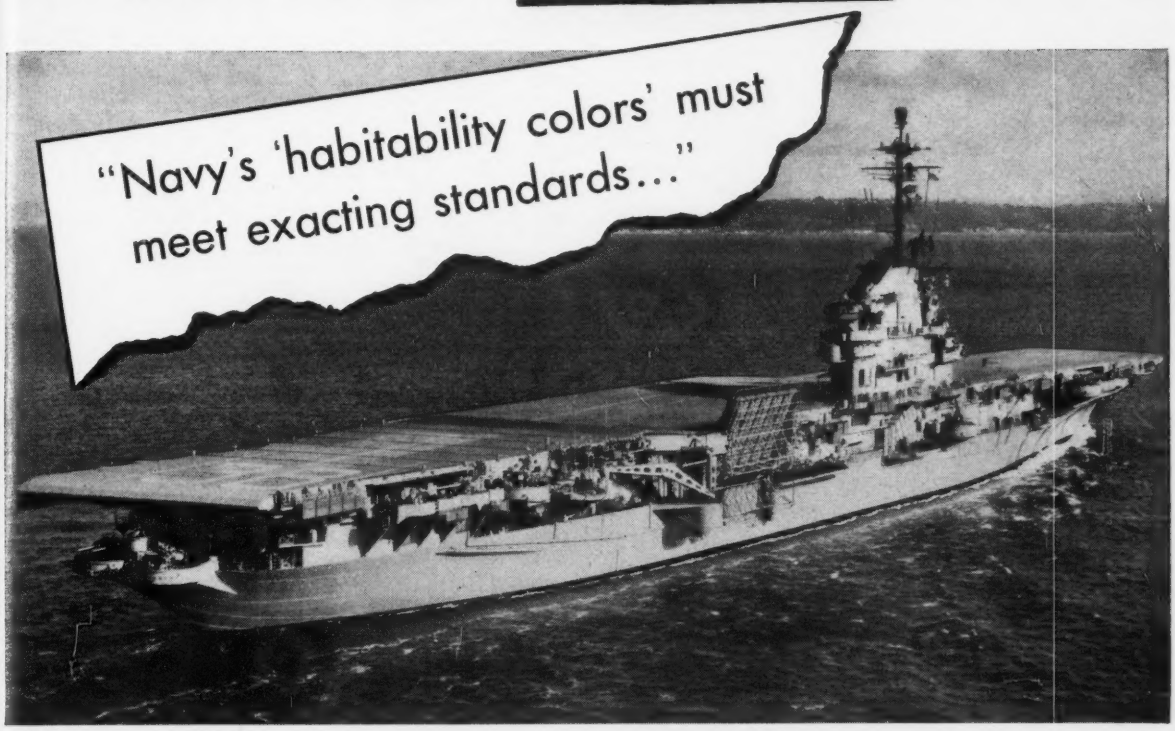
Call or write today for estimates or quotations. Let our stockholder-employees demonstrate the economical and satisfactory service they can give you.

CSI

CORROSION SERVICES INCORPORATED
Tulsa, Oklahoma

P. O. Box 7343, Dept. F **Telephone: Gibson 7-0082**

Parlon® Stays On!



Official photograph, U. S. Navy

In 1948 the Navy began experiments with colors for the interiors of its ships. Getting the right colors was the easy part. What was needed was a coating that had resistance to soil, was easy to clean, could be put on over old paint or standard primers, was stable enough for long storage periods, and could be made fire-retardant!

Of all the formulations tested, only two could meet the severe requirements. One was a baked-on enamel, impractical for Navy maintenance programs. The other was an air-drying alkyd finish based on Hercules Parlon (chlorinated rubber).

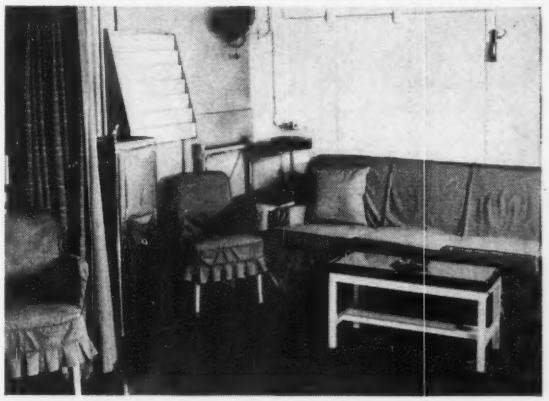
Parlon-based paints have been meeting such unusual requirements wherever they occur. Whenever protective coatings must take a beating, wherever they must meet the challenge of corrosion from weather, acid or alkali, Parlon formulations provide longer service at lower long-term cost. See your dealer or write Hercules for details on Parlon-based coatings.

Cellulose Products Department
HERCULES POWDER COMPANY
INCORPORATED
999 King St., Wilmington 99, Del.

CR55-4

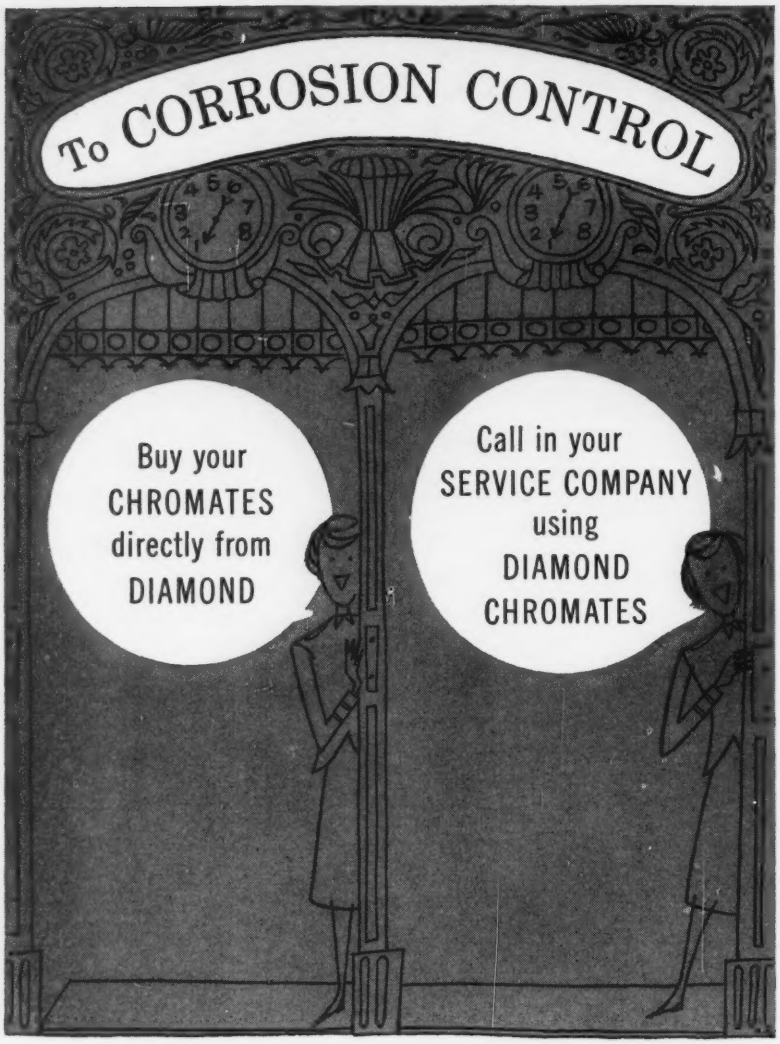
NEW LOOK FOR FLAT TOPS—Color is one of the major factors in improving the appearance of living space. That's why the Navy has abandoned its traditionally drab color schemes in favor of interior paints in nine pastel shades.

Official photograph, U. S. Navy



THE COMFORTS OF HOME—This typical interior of a Navy surface craft provides all the comforts of home, and today may be decorated in colors ranging from beach sand to sunglow.

PARLON CHLORINATED RUBBER PAINTS ARE AVAILABLE FROM 400 MANUFACTURERS UNDER THEIR OWN BRAND NAMES



Either way, results go up

Some companies buy chemicals for corrosion control. Others call in a reliable service organization for this important job.

The wisest companies, no matter which method they use, make sure they get full value by specifying DIAMOND corrosion control chemicals—sodium chromate and sodium bichromate—for the job. DIAMOND can deliver quickly to your plant from strategically located stocks.

DIAMOND offers technical help and service on problems involving corrosion control. Call your DIAMOND Sales Office in Chicago, Cincinnati, Cleveland, Houston, Memphis, New York, Philadelphia, Pittsburgh or St. Louis.

Or write to DIAMOND ALKALI COMPANY, 300 Union Commerce Building, Cleveland 14, Ohio.

DIAMOND ALKALI CHEMICALS

Diamond Chemicals

NEW PRODUCTS

(Continued from Page 94)

Molykote Lubricants, made by the Alphy Molykote Corp., 65 Harvard Ave., Stamford, Conn., are described in a four-page bulletin. The lubricants are designed for extremely high bearing pressures. A chart is included which describes each Molykote type lubricant, the kind of carrier used in it, the temperature range in which it operates best and the proper method of application.

•

Carboloy Department of General Electric Co., Detroit 32, Mich. reports it has developed a method of applying thin layers of tungsten carbide to form a metallurgical bond with steel surfaces. Cemented carbides have been applied to various pieces of machinery in thicknesses up to 0.030-inch. Carboloy engineers also are testing the possibility for use as sheet material, the high-strength vacuum melted super alloy 1570 developed for jet aircraft turbine buckets.

•

Haveg Corp., 900 Greenbank Rd., Wilmington 8, Del., has published a 32-page illustrated catalog describing corrosion-resistant equipment the firm manufactures. The catalog features new materials of construction, evaluates equipment molded from polyvinyl chloride, epoxy glass and polyester glass, and gives data on their resistance to chemicals and heat. The corrosion resistant materials are used in making piping, tanks, exhaust fans and ducts, valves and other uses. The firm also makes special corrosion resistant cements.

•

Alco Products, Inc., Schenectady 5, N. Y., describes maximum accident precautions and gives some details of the first nuclear power plant to be installed in the Washington, D. C. area by Alco products.

•

Koppers Co., Inc., Pittsburgh 19, Pa. has purchased all assets of Turner & Haws Engineering Co., Inc. of West Roxbury, Mass., makers of a special line of filters for cleaning industrial air or gas. Purpose in acquiring the new business is to provide the industry with a complete line of modern equipment for recovery of valuable solids carried in gases which may be reused or other solids which pollute air when exhausted from industrial processes, according to Koppers spokesman.

•

Camac Karbate falling film hydrochloric acid absorbers designed for laboratory and pilot plant applications are made by Carl Buck & Associates, Essex Falls, N. J. Units are available in capacities of 15, 30 and 45 lb. per hour of hydrochloric acid gas. Design provides for delivery of cool stable acid up to 22 degrees Be concentration.

•

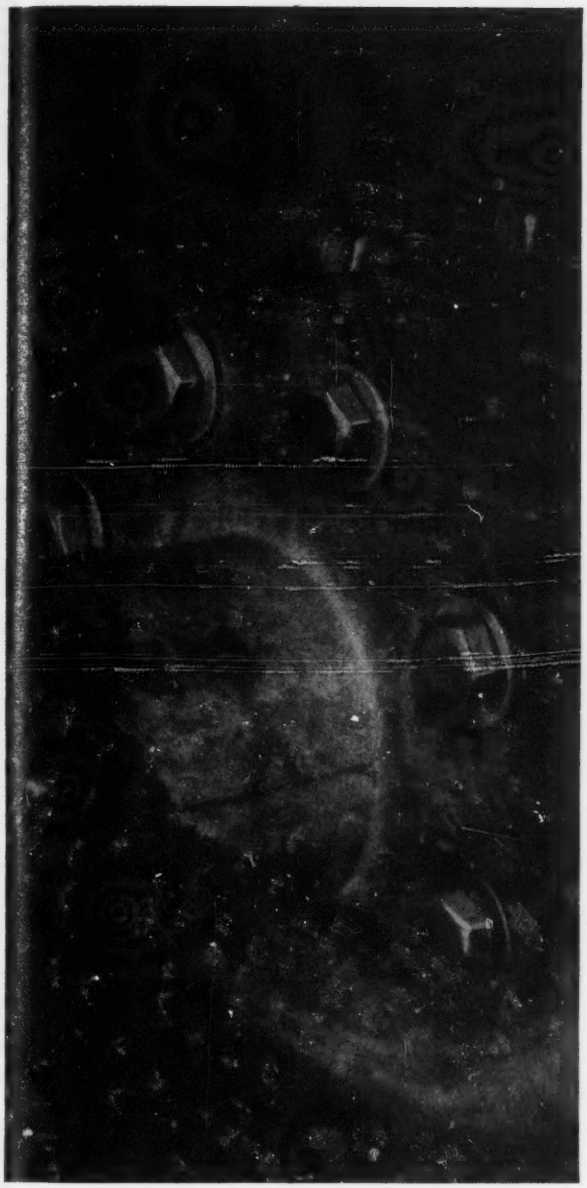
Plico, Inc., Los Angeles, Calif. has published a new service manual describing the proper use and applications of pipeline enamels and primers. The manual covers 27 steps of procedure and contains a number of useful specification tables. Cleaning, priming and coating of line pipe with hot applied asphaltic pipe enamels are discussed.

•

General Ceramics Corp., Chemical

(Continued on Page 98)

Fittings stay fastened in Corrosive Acid Spray



PROBLEM:

Selecting fastenings that would hold pipe fittings together in a unit that is constantly subjected to a hot sulphuric acid spray. Bolts were formerly falling apart in four months' time.

REMEDY:

Use of nuts and bolts made of wrought HASTELLOY alloy C.

RESULT:

Fastenings made of HASTELLOY alloy C are still holding many months after ordinary bolts had to be replaced.

HASTELLOY alloy C is the most universally corrosion-resistant alloy available today. In addition to aerated sulphuric acid, it has excellent resistance to such strong oxidizers as nitric acid, wet and dry chlorine, and acid solutions of salts. It is available in nearly all standard commercial forms.

For more information on HASTELLOY alloy C, get in touch with the nearest Haynes Stellite Company Office.

HAYNES TRADE-MARK ALLOYS

HAYNES STELLITE COMPANY

A Division of Union Carbide and Carbon Corporation

UCC

General Offices and Works, Kokomo, Indiana

Sales Offices

Chicago • Cleveland • Detroit • Houston • Los Angeles • New York • San Francisco • Tulsa

"Haynes" and "Hastelloy" are registered trade-marks of Union Carbide and Carbon Corporation

NEW PRODUCTS

(Continued From Page 96)

Equipment Div., Keasbey, N. J. has developed a new fast service for the relining of glass-lined chemical equipment. Use of a special acid and alkali resistant enamel makes it possible to give quick, efficient service, the company states.

•

Harvey Aluminum, 19200 S. Western Ave., Torrance, Calif., is conducting a project to provide manufacturers with technical assistance in formulating new commercial uses for aluminum forgings. The latest information on engineering design, press forge facilities, metallurgical and production advances will be made available to all who request it. Industrial designers and engineers are invited to write to the firm for information.

•

Dynel, made by the textile fibers department of Carbide and Carbon Chemicals Co., 30 E. 42nd St., New York 17, N. Y., is strongly resistant to acid and caustic soda, the manufacturers claim. Work uniforms made of Dynel last as much as 20 times as long as regular uniforms in use by cleaning and plating operators at the Army Ordnance Corps' Picatinny Arsenal.

•

Aluminum Company of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa. is now manufacturing aluminum in all colors of the rainbow. Color finishes are actually part of the metal itself. The crystal-clear, diamond-hard oxide coating on all aluminum is artificially built up and colored with special dye materials. The color becomes an integral part of the metal. The colored aluminum is available in sheet, tube and extruded shapes.

•

Alcoa has published an 18-page booklet entitled Aluminum Pipe and Fittings which presents the characteristics and advantages for each of the major fields of application of aluminum pipe. Specifications are provided along with a description of appropriate fittings and methods of installation.

•

Amercoat Corporation, 4809 Firestone Blvd., South Gate, Cal., makers of T-Lock Amer-Plate Sewer Lining recently published an 8-page brochure describing the product and its uses. The booklet provides complete information on its composition, physical and chemical properties and the method of incorporating the lining in pre-cast and cast-in-place concrete sewer pipe and structures.

•

Bio-Rad Laboratories, 800 Delaware St., Berkeley, Calif., have printed a price list of two new products; analytical grade chromatographic alumina, and anion exchange resins which have been treated with an indicating dye to change color reversibly in going from the hydroxide to other ionic forms.

•

The Carborundum Co., Niagara Falls, N. Y. will install an electronic data processing system using Univac as its central electronic file computer. The electronic "brain" will, it is predicted, give management important facts quickly. It will make possible better planning and sharper management control of business.

•

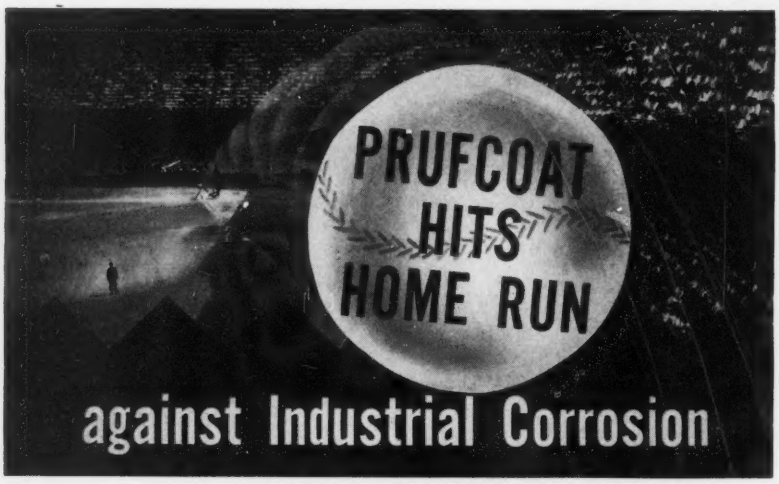
Rubber Insulated metal parts such as slips, harness, clamps and grommets manufactured by Arco, 12550 Beech Road, Detroit 39, Mich., are described and illustrated in a phamphlet "Form Dipped Rubber Parts."

•

Hygrometric humidity controller made by American Instrument Co., Inc., Silver Spring, Md., controls action of humidifiers, dehumidifiers and air conditioners within plus or minus 1.25 percent relative humidity.

•

Educt-O-Matic, an abrasive cleaning unit which provides contained, dust-free and safe blast cleaning is manufactured by Clementina, Ltd., San Francisco, Cal. and distributed in Southwestern states by Clemtex, Inc., P. O. Box 15214, Houston 20, Texas. The 6-lb. device permits blast cleaning overhead, underfoot or at any angle with abrasives which are recirculated continuously. Dust is separated from the abrasive stream and collected in a bag. By means of a vacuum tube surrounding the blast nozzle the abrasive and loosened coatings, rust, or other material is returned through the system and does not affect the immediate surroundings in which the cleaning is done. The manufacturers recommend the device for use in plants under operating conditions, or where blasting has not been considered before because of hazards to personel or products. Low initial cost of the tool can be returned in 30 to 60 days by increased production, according to the manufacturers. Demonstration of the tool is available on application to Clemtex or any Clementina distributor.



These 4 great, new Anti-Corrosion products lead the league!

1 **PRUFCOAT New "A" Hot-Spray Vinyl Gives Greater Mil Thickness, Improved Film Density, Better Adhesion — at Lower Cost!**

Now, performance-proven Prufcoat "A" Series Vinyl has been adapted and specifically engineered for the modern, cost-saving technique of hot-spray. Prufcoat "A" Hot-Spray gives you *greater mil thickness* (4-5 mils in a single spray pass), *improved film density* (no porosity or pinholing) and *better adhesion* (to primers and even bare metal) at *lower cost* per sq. ft. of surface.

2 **New! PRUFCOAT Odorless Chemical-Resistant Coatings Eliminate Chemical-Resistant Painting Odor Problems**

Prufcoat Odorless Chemical-Resistant Coatings provide high resistance to acids, alkalies, and other chemicals. Scrubbable 24 hours after application, they withstand extensive scouring and cleaning. Ideal for use in confined, poorly ventilated areas. Suitable for application over wood, metal, or concrete. No wrinkling or lifting of old paints. Easy to apply, and supplied in a variety of colors.

3 **PRUFCOAT New Fast-Dry Primer P-50 Lets You Over-Coat In Just Two Hours!** The famous Prufcoat Primer P-50 now with 2-hour drying action! You do your complete coating job from primer to top coat in just one day. This heavy bodied, rust inhibitive oleoresinous metal primer insures 2 mils or more thickness in the prime coat alone. Minimum surface preparation needed, yet there is positive adhesion and underfilm corrosion control.

4 **PRUFCOAT "Gloss" Mastic The Perfected Vinyl Base Mastic with "Gloss" Finish that Improves Chemical Resistance, Gives Better Appearance.**

This exclusive mastic formulation, based on vinyl and other chemical-resistant resins, gives exceptionally heavy build in cross-coat spray application, using conventional cold spray equipment. Prufcoat "Gloss" Mastic provides a tough and substantial coating over rough and hard-to-protect structural or machine areas.

Get these Prufcoat winners, engineered and test-proven to solve the toughest corrosion problems, going to bat *for you* in your fight against corrosion. Without obligation, write today for complete information.

PRUFCOAT LABORATORIES INCORPORATED

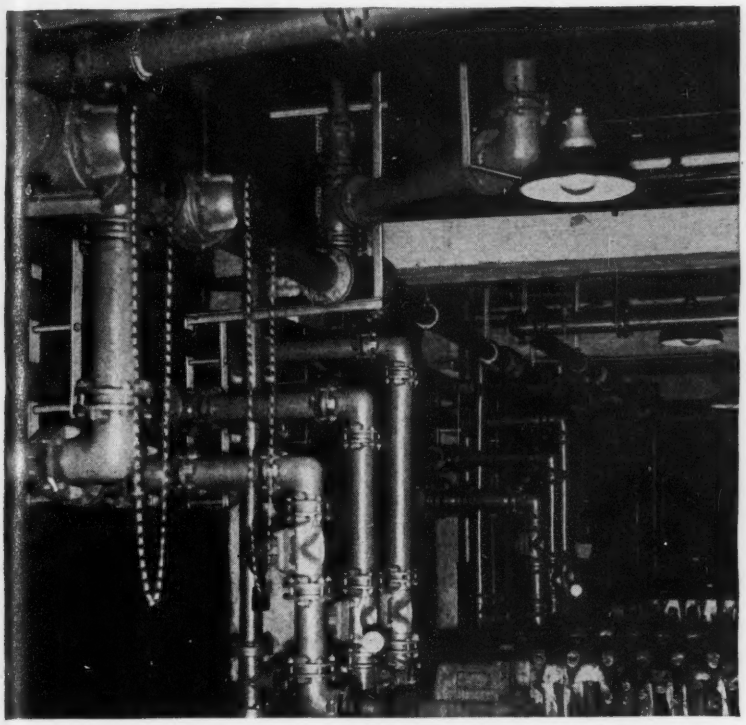
Sales Office: 50 E. 42nd Street, New York 17, N. Y.

Plant: 63 Main Street, Cambridge 42, Mass.

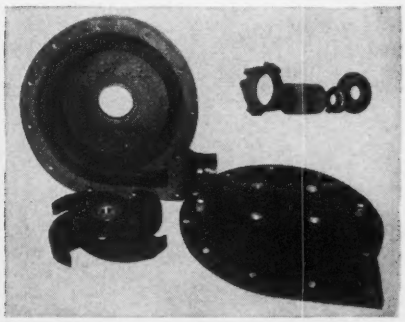
WHERE HAVEG EQUIPMENT IS INSTALLED

TRADE MARK REG. U. S. PAT. OFF.

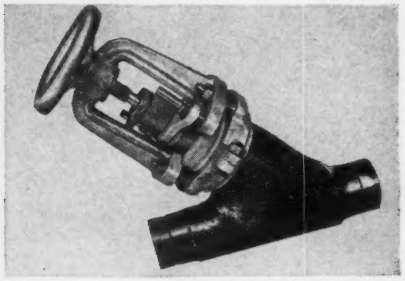
PIPE • DUCT • FITTINGS • VALVES • PUMPS



A typical large installation of Haveg pipe, valves and fittings showing simple method of support required. Haveg pipe is unaffected by thermal shock, seldom requires insulation.



These Haveg parts are used in pumps for hot (104°F.) 30% Hydrochloric acid. Typical record: 33 months without replacing a single part. Many users report even longer life.



Escape potential valve troubles by buying Haveg y-valves and diaphragm valves which are smooth-molded, exactingly machined, tested in the Haveg factory. Haveg works with you on special designs!

Processing Corrosion has been Controlled!

Where liquids get hot and corrosive, it pays to consider all the facts about Haveg piping systems. Haveg has all the major ingredients for good chemical piping. Strength. Durability. Light weight. Outstanding resistance to corrosion and thermal shock.

It withstands rapid temperature changes and enables you to go into a high range of process temperatures with complete safety and a proven history of reliable performance. Haveg piping resists corrosion of practically all acids (except oxidizing acids) and lasts for years without repairs or maintenance.

Haveg *piping* is molded in diameters of ½" up and comes in lengths to 10'. It can be cut and fitted on the job (a new Haveg tool makes this even simpler—ask your Haveg engineer for details). For handling corrosive gases or fumes, Haveg *duct* is made in cylindrical or rectangular shape with lighter walls. Fume hoods, bifurcators, fan housings, fittings, all are made from Haveg and give complete containment and control of corrosives.

It's a long story telling all about Haveg, the moldable, thermosetting plastic material made of acid-digested asbestos and synthetic resins. Haveg is both a material and a service . . . it comes from America's first molders of corrosion-resistant plastic equipment. It can be as big as a 200' stack, as small as a miniature pump part. Call the experienced sales engineer listed. Write for the 64-page illustrated Bulletin F-6 which contains size and chemical resistance charts, design specifications. Remember, Haveg is a logical, proven answer to your design problems in handling hot, corrosive liquids; in fact, in all equipment that must control processing corrosion.

ATLANTA 5, Exchange 3821 • DETROIT 39, Kenwood 1-1785
CHICAGO 11, DElaware 7-6088 • HOUSTON 4, Jackson 2-6840
CLEVELAND 20, Washington 1-8700 • LOS ANGELES 14, Mutual 1105
WESTFIELD, N. J., Westfield 2-7383

HAVEG CORPORATION
TRADE MARK REG. U. S. PAT. OFF.
A SUBSIDIARY OF HAVEG INDUSTRIES, INC.
912 GREENBANK ROAD • WILMINGTON 2, DEL. WYman 8-2276

You can solve your **tough** corrosion problems by using Bitumastic® Coatings

ACID FUMES, alkaline fumes and high humidity soon corrode unprotected metal in textile mills. These dye tanks, in a large New England worsted mill, are coated with Bitumastic® Black Solution. For over six years, this specialized coating has been used successfully to protect these tanks against corrosive chemical agents and moisture.

TOUGH CORROSION PROBLEMS can be solved, but not by using ordinary paints or conventional protective coatings. For long-term protection, it takes *specialized* protective coatings . . . the Bitumastic Coatings Koppers makes.

Bitumastic Protective Coatings are specially formulated from a tar-pitch base* that is, for all practical purposes, impervious to moisture. These coatings keep moisture away from exposed metal surfaces . . . and that's the *best* way to stop corrosion.

With tough, durable Bitumastic Protective Coatings, a thickness up to eight times that of ordinary paints can be obtained in one application. Where other factors are equal, the *thicker* the coating the *longer* the period of protection.

Send for a set of free booklets describing the family of Bitumastic Protective Coatings. At the same time, tell us about *your* corrosion problems so that we can suggest a satisfactory solution. There is no obligation, of course.

** Hi-Heat Gray is a non-coal-tar vehicle and metallic pigment.*

KOPPERS COMPANY, INC.
Tar Products Division, 1204-T, Pittsburgh 19, Pennsylvania
DISTRICT OFFICES: BOSTON, CHICAGO, LOS ANGELES, NEW YORK, PITTSBURGH, AND WOODWARD, ALA.
KOPPERS PRODUCTS LIMITED District Offices: Toronto & Edmonton

MADE ONLY BY KOPPERS
BITUMASTIC PROTECTIVE COATINGS
REG. U.S. PAT. OFF.
SOLD THROUGH INDUSTRIAL DISTRIBUTORS
KOPPERS ®

PERSONALS

R. N. Hillner has been named manager of products sales for H. M. Harper Co., Morton Grove, Ill. **John A. Stephenson** has been named manager of technical sales by the Aero Division of the company.

•

Lester E. Johnson has been named Supervisor of the Industrial Chemicals Section of the Development and Research Division of The International Nickel Co., Inc., New York.

•

Herbert A. Merrill has been made Chief Inspector, Quality Control for Portland Copper and Tank Works, Inc., South Portland, Me.

•

Bernard R. Schaafsma has been promoted to the position of assistant director of research at Colgate-Palmolive Company. He will have charge of research activities at the Synthetic Detergents Div., Soaps Div., Mechanical Engineering and Pilot Plants. He is a graduate of Calvin College, Grand Rapids, Mich. and has a PhD in organic chemistry from Indiana University.

•

Harold L. Danziger has been promoted to general sales manager for R. M. Hollingshead Corp., where he will supervise all sales activities of the various sales divisions plus the advertising and market research departments. He previously was group manager in charge of the automotive, special brands and universal divisions of the corporation.

•

Harry Ivan Sullivan and **Jack Spence** have formed a new corporation, Spence & Sullivan, Inc., 344 E. Carson St., Torrance, Cal. The firm specializes in sandblasting, application of rust inhibitive coatings for pipe lines, tanks, penstocks and structural steel. The partners formed the new firm by purchasing the O'Connor Rust-Proofing Co. Mr. Sullivan is a member of National Association of Corrosion Engineers.

•

Appointment of **Joseph E. Mihm** as assistant vice-president of the Walworth Co., manufacturers of valves and pipe fittings was announced recently. He will be in charge of Walworth's West Coast operations with headquarters in San Francisco.

•

Clare W. Russ has been appointed vice-president and director of sales for the Metalene Chemical Co., 34-40 S. Park St., Bedford, Ohio. He will have complete charge of the firm's sales program. He has been with the company 10 years.

•

William L. Clark has been appointed product manager of Alcoplate process, owned by Alco Products, Inc. He will be in charge of all phases of production, marketing and research involved in the new method of chemical nickel plating. He is a member of National Association of Corrosion Engineers and is the author of a paper presented at the South Central Regional NACE meeting, held during October at the Shamrock-Hilton Hotel, Houston. Title of the paper was "Alcoplate—A New Material for the Corrosion Engineer."

•

Dr. Joseph B. Ennis, a world authority

(Continued on Page 102)

JUST OFF THE PRESS!
now you can see Harco "at work"
CATHODIC PROTECTION SYSTEMS
FOR CORROSION CONTROL
THE Harco CORPORATION

Here's the Inside Story on Corrosion Control

Now . . . for the first time . . . down-to-fact information is available which reveals the actual causes of pipe line corrosion . . . and how the destructive force can be halted.

Complete with actual photos, technical drawings and informative diagrams and charts, this new brochure deals with all types of cathodic protection for metal structures, pipe and other ferrous components which come into contact with ground or water.

One complete section is devoted to the protection of water works equipment and storage tanks.

Use the convenient coupon below to get your copy of "Cathodic Protection Systems for Corrosion Control". It will insure that you're not "missing any bets" for maximum operating economy . . . and it will help in making top management decisions to protect your equipment.

GET YOUR FREE COPY TODAY

THE Harco CORPORATION
CATHODIC PROTECTION DIVISION
16991 Broadway • Cleveland, Ohio

6617-HC

THE HARCO CORPORATION, Dept.
16991 Broadway, Cleveland, Ohio

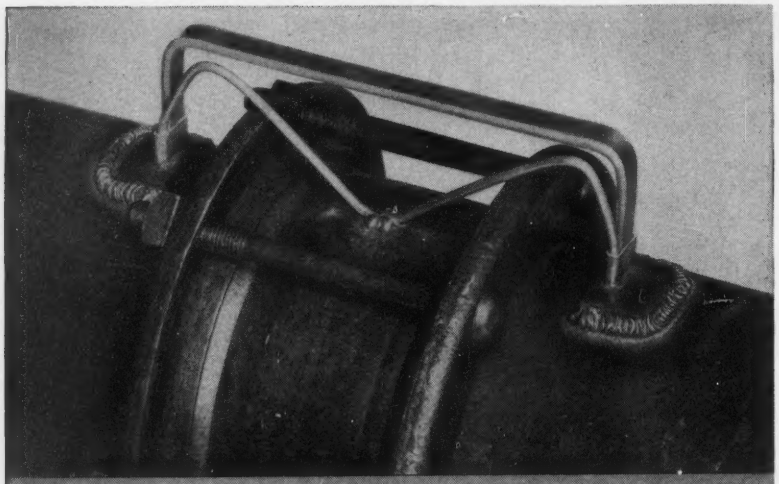
Please send me a copy of your technical brochure "Cathodic Protection Systems for Corrosion Control".

Name _____ Title _____

Company _____

Address _____

City _____ State _____



How to cut the cost of preventing electrolytic corrosion of pipe

FIGHT CORROSION
with easy to apply
American Devices

1. **Pipe Coupling Shunts**
2. **Anode Connectors**
3. **Suspended Anode Connectors for piers, dry docks, ships, etc.**
4. **Coupon Connectors for connecting leads to pipe.**

You have to protect underground pipe from electrolytic corrosion. But homemade shunts cost too much—in time and labor.

There's an easy solution to this problem: use prefabricated American Pipe Coupling Shunts. They are designed especially for use on mechanical pipe couplings. Terminals on the shunts are steel, curved to fit the pipe. Heavy, copper bar main conductors and steel secondary conductors — welded permanently to the pipe and coupling — keep the assembly at the same potential.

Write for complete information about this and other cathodic protection devices manufactured by American Steel & Wire.

AMERICAN STEEL & WIRE
DIVISION
UNITED STATES STEEL
GENERAL OFFICES: CLEVELAND, OHIO
COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO, PACIFIC COAST DISTRIBUTORS
TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA., SOUTHERN DISTRIBUTORS
UNITED STATES STEEL EXPORT COMPANY, NEW YORK

USS AMERICAN PIPE COUPLING SHUNTS

UNITED STATES STEEL

PERSONALS

(Continued From Page 100)

on steam locomotive power and former senior vice president of American Locomotive Co. died Sept. 22 at the age of 76 in Paterson, N. J.

•

Walter S. Clavan, Pennsalt research chemist, has been advanced to the position of group leader. In this capacity, he will supervise research activities in the company's analytical department at the Whitemarsh research and development laboratories.

•

M. G. Kennedy has been appointed manager of the sales, marketing and public relations department of Ebasco Services, Inc. The department Mr. Kennedy heads provides consulting services to clients.

•

E. M. Uebel and **K. H. Kirgin** have joined the ductile iron section of the International Nickel Company's development and research division. The section is being expanded because of the increasing acceptance of ductile iron, which was invented and developed by Inco.

•

Karl Schumpelt has been appointed chief metallurgist for Sel-Rex Precious Metals, Inc., Belleville, N. J. Mr. Schumpelt, a graduate of the Berlin Institute of Technology and the University of Berlin will devote most of his time to research and development.

•

Federated Metals Division, American Smelting and Refining Co., New York, N. Y. has shifted and promoted three men. **George M. Baumann** has been transferred to New York as assistant to **Frederick Walker** who is an assistant to the president of the firm. **James F. McQuillan** succeeds Mr. Baumann as assistant general manager of the Midwestern department and **M. Robert Herman** assumes Mr. McQuillan's position of manager of the Houston plant.

•

Owen Rice, vice-president in charge of industrial chemical sales for Hagan Corp., Pittsburgh, Pa. has been elected a director of Hagan and its subsidiaries, Calgon, Inc., Hall Laboratories, Inc. and the Buromin Co. Mr. Rice fills a vacancy on the board created when **E. M. Chaney** retired as company treasurer and director.

•

Appointment of **DuBose Avery** as manager of architectural sales and **E. M. Strauss, Jr.** as manager of the commercial research division has been announced by Aluminum Company of America.

•

J. L. Varga has been named manager of the Pacific Division, Ladish Co. The firm, manufacturer of drop forgings, pipe fittings and rolled rings purchased two adjacent Los Angeles manufacturing plants and designated Mr. Varga to head them.

•

Royston Laboratories, Inc., Blawnox (Pittsburgh), Pa., manufacturers of corrosion-resistant coatings, recently announced the appointment of **Harry N. Strothman** as regional sales engineer in charge of its new Chicago office.

•

An index to the Technical Committee Activities Section in Corrosion is published annually in December.

Corrosion Abstracts

CORROSION CONTROL — PROTECTED INDUSTRY — NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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Vol. 11 December, 1955 No. 12

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3. CHARACTERISTIC CORROSION PHENOMENA

3.7 Metallurgical Effects

3.7.3, 6.4.2

Effects of Cold Working on Corrosion of High Purity Aluminum in Water at High Temperatures. M. J. LAVIGNE. Chalk River Project (Canada). U. S. Atomic Energy Comm. Pubn., MET. I.-3, November 4, 1954, 18 pp.

The effects of cold-working and cold-working and annealing to complete recrystallization on the corrosion resistance of high-purity aluminum in water at 100, 150 and 200 C have been determined. In distilled water at 100 C, high-purity aluminum cold worked 5 to 50 percent inclusive and all the recrystallized aluminum corrode intergranularly, but materials cold-worked 60 percent and over are immune against this attack. At 150 and 200 C, the 60 and 70 percent cold-worked materials corrode intergranularly while the 80 and 90 percent cold-worked corrode generally. The attack on the latter materials appears to be also selective as some grains corrode preferentially to others. (auth).—NSA. 9155

3.7.3, 6.4.2

The Spot Welding of Aluminium Alloys: Machine Developments and Research Progress. H. E. DIXON. *Welding and Met. Fabrication*, **22**, Nos. 9, 10, 350-353, 384-387 (1954) Sept., Oct.

Reviews developments in spot welding machines, current cycles, welding specifications, effect of welding variables, mechanical properties of welds (including fatigue properties), applications. 37 references.—BNF. 9272

3.8 Miscellaneous Principles

3.8.4, 3.2.3, 6.5

Contribution to the Study of Hot Oxidation of Metals and Alloys. (In Italian). F. DE CARLI AND P. SPINEDI. *Metallurgia italiana*, **46**, special supplement to No. 5, 101-107; disc., 107 (1954) May.

Tests on iron, copper, titanium, copper-tin and copper-aluminum. Effects of allotropic modifications, stability of oxides, composition of oxidized layers and composition of alloys. Diagrams. Eighteen references.—BTR. 9262

3.8.4, 3.5.9

Investigation of Oxidation Processes of Iron Powder at High Temperatures. (In Russian). P. D. DANKOV AND N. K. ANDRUSCHENKO. *J. Phys. Chem. USSR* (Zhurnal Fizicheskoi Khimii), **28**, No. 3, 519-524 (1954) March.

Oxidation velocity at 200, 400, 600, 800 and 1000 C. 3 references.—BTR. 9260

3.8.4, 4.3.2, 6.3.15, 6.3.20, 6.3.21

The Reaction of Metallic Titanium, Zirconium, Hafnium and Thorium With Acids, Especially With Hydrofluoric Acid. (In German). M. E. STRAUMANIS AND J. I. BALLASS. *Z. anorg. u. allgem. Chem.*, **278**, No. ½, 33-41 (1955) Jan.

Of the four metals titanium, zirconium, hafnium, and thorium, thorium is the most resistant to the action of acids. It dissolves very slowly, probably with the

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AWWA—Journal, American Water Works Association, Amer. Water Works Asoc., 521 Fifth Ave., New York 17, N. Y.

BL—Current Technical Literature, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

BTR—Battelle Technical Review, Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.

BNF—Bulletin; British Non-Ferrous Metals Research Association. 81-91 Euston St., London NW 1, England.

CBEC—Centre Belge d'Etude de la Corrosion (CEBELCOR), 17 re des Drapiers, Brussels, Belgium.

CE—Chemical Engineering, McGraw Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

EL—Electroplating. 83/85 Udney Park Road, Teddington, Middlesex, England.

EW—Electrical World, McGraw-Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

GPC—General Petroleum Corp. of California. 2525 East 37th St., Los Angeles 11, Calif.

IIM—Transactions, The Indian Institute of Metals, 23-B, Notaji Subhas Road, P. O. Box 737, Calcutta, India.

INCO—The International Nickel Co., Inc. 67 Wall Street, New York 5, New York.

IP—Institute of Petroleum. 26 Portland Place, London W#1, England.

JSPS—Japan Society for the Promotion of Science, Address: Mr. Hayata Shigeno, Secretary, Committee of Preventing Corrosion, c/o Government Chemical Industrial Research Institute, 1-Chrome Nakameguro, Meguro-ku, Tokyo, Japan.

MA—Metallurgical Abstracts, Institute of Metals, London, England. 4 Grosvenor Gardens, London SW 1, England.

MI—Metallurgia Italiana, Associazone Italiana di Metallurgia. Via S. Paola, 10, Milano, Italia.

MR—Metals Review, American Society of Metals. 7301 Euclid Ave., Cleveland 3, Ohio.

NALCO—National Aluminate Corp. 6216 West 66th Place, Chicago 38, Illinois.

NBS—National Bureau of Standards. Supt. of Documents, U. S. Gov't Printing Office, Washington 25, D. C.

NSA—Nuclear Science Abstracts. United States Atomic Energy Commission, Technical Information Division, Oak Ridge, Tenn.

PDA—Prevention Deterioration Abstracts. National Research Council, 2101 Constitution Ave., Washington 25, D. C.

RM—Revue de Metallurgie, Paris, France. 5 Cite Pigalle, Paris (9e), France.

RPI—Review of Current Literature Relating to the Paint, Colour, Varnish and Allied Industries, Research Association of British Paint, Colour & Varnish Manufacturers, London, Waldegrave Rd., Teddington, Middlesex.

SE—Stahl Und Eisen, Verlag Stahleisen, M. B. H., Dusseldorf, August-Thysen Str. 1. Postscheck Koln 4110, (22a) Dusseldorf, Germany.

TIME—Transactions of Institute of Marine Engineers. 85 The Minories, London EC 3, England.

UOP—Universal Oil Products. 310 South Michigan Ave., Chicago, Illinois.

ZDA—Zinc Development Association. 34 Berkeley Square, London W.1.

formation of tetravalent ions in hydrofluoric, hydrochloric and sulfuric acids. Aqua regia, in comparison, works most rapidly. The action of other acids is rapid or completely ineffective. The behavior of the first three metals in the different acids is very similar. They dissolve rapidly in hydrofluoric acid and also in diluted acids with the evolution of hydrogen.—NSA. 9223

3.8.4, 6.2.2, 2.3.9

Use of Fe^{59} for Investigating the Mechanism of Iron Oxidation. (In Russian). B. V. LINCHEVSKII AND N. P. ZHUK. *J. Phys. Chem. USSR* (Zhurnal Fizicheskoi Khimii), **28**, No. 12, 2265-2267 (1954) Dec.

Experimental data on the distribution of activity in iron scale. Graphs, table. 5 references.—BTR. 9152

3.8.4, 6.3.3

The Effects of Space-Charge on the Rate of Formation of Anode Films (on Tantalum). (In English). JACOB F. DEWALD. *Acta Metallurgica*, **2**, No. 2, 340-341 (1954).

A letter. Dewald comments on three discrepancies between the theory of thin films due to Mott and Cabrera and the recent results of Vermilyea for anodic growth on tantalum [*ibid.*, **1**, 282 (1953)]. i) The rate of charge of field with ln formation-rate was found to be temperature-independent, instead of αT as predicted. This is due to neglect of space-charge effects in the theory; modified equations for the elect. field, including space charge, are given. ii) Vermilyea reported a frequency factor of 10^{-2} instead of the expected 10^{13}. iii) The fields observed should have been sufficient to obliterate the barrier for diffusion. The last two "discrepancies" are shown to be due to misapplication of the original theory. 2 references. —MA. 9271

3.8.4, 6.3.21, 4.3.5

Reaction of Nitrogen with and the Diffusion of Nitrogen in Thorium. A. F. GERDS AND M. W. MALLETT. *J. Electrochem. Soc.*, **101**, No. 4, 175-180 (1954).

Rates of reaction of nitrogen with thorium were determined for the temperature range 670-1490 C at one atmosphere pressure; the reaction followed a parabolic rate law with a rate constant 5.9 exp (—24,300/RT) (ml/cm.²)²/sec. Over the temperature range 845-1490 C the diffusion coefficient of nitrogen in thorium was found to be 2.1×10^{-3} exp (—22,500/RT) cm²/sec. Limiting solubilities of nitrogen were determined from the diffusion data. The heat of solution of atomic nitrogen (from ThN) in thorium is 11,000 cal./mole. 13 references.—MA. 9239

4. CORROSIVE ENVIRONMENTS

4.2 Atmospheric

4.2.1, 1.4

Air Pollution: A Bibliography. S. J. DAVENPORT AND G. G. MORGIS. U. S. Bureau of Mines Bull. No. 537, 1954, 448 pp. Available from: U. S. Supt. of Documents, Washington 25, D. C.

3902 references under the headings: general aspects; nature and origin of air pollution; composition of pollutants; effects on health, structures, materials and vegetation; methods of determination; control (general measures, mechanical aids, collection and precipitation); legal aspects and cost. An author index is provided.—BNF. 9270

4.4 Chemicals, Organic

4.4.7, 2.3.4

Laboratory Corrosion Tests with Heated Motor-Car Engine Oils for the Assessment of the Effectiveness of "Premium" Additives. (In German). A. BUKOWIECKI. *Schweiz. Archiv. angew. Wiss. u. Tech.*, **20**, No. 8, 255-263 (1954) August.

The corrosion of lead bronze or cadmium-2 percent nickel bearings by the cooling oil at the operating temperature of modern internal combustion engines is inhibited by "Premium" or "Heavy-Duty" additives to the oil. A variety of tests are employed for quality control of these oils and experiments are described on the effect of slight variations in testing conditions with the object of developing a standard routine test. A large number of commercial oils of good quality were used for the experiments and the test conditions were regarded as satisfactory when they graded the oils according to their known categories. Effects of air and viscosity are covered. The validity of the test was confirmed by experiments with laboratory mixtures of oils and additives, which also demonstrated that

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higher concentration of inhibitors permitted longer test duration before the corrosion rate increased. The reproducibility of results is not very accurate, but it is sufficient for grading oils and supervising consistency of deliveries. 19 references.—MA. 9227

4.6 Water and Steam

4.6.4, 5.9.2, 8.4.5, 1.6

Corrosion of Reactor Structural Materials in High-Temperature Water. Part I. Descaling Methods. Part II. Static Corrosion Behavior at 600 to 680 F. R. Fowler, Jr., D. L. Douglas and F. C. Zyzes. Knolls Atomic Power Lab. U. S. Atomic Energy Comm. Pubns. (I). KAPL-1198, August 27, 1954, 30 pp. (II). KAPL-1248, December 1, 1954, 75 pp.

I. Three descaling techniques found suitable for removing the oxide layers formed on ferrous and nickel alloys when the latter are corroded in high-temperature water are 1) cathodic treatment in inhibited sulfuric acid, 2) immersion in a sodium hydride bath, and 3) immersion in Clarke's solution. The results of an extensive investigation of the descaling blanks, the materials for which each descaling procedure is effective, and important variables are reported. (auth).

II. Possible structural materials for use in the primary coolant system and for fuel element fabrication in a water-cooled and moderated reactor were extensively corrosion tested in static water and various aqueous media at 600 and 680 F. Both AISI Type 304 and stainless steels were found to react with water at these temperatures at a rate of 3 to 5 mg of metal/dm²/500 hr. Carbon steel (ASTM A201) corroded at a rate approximately 10 times greater (40 mg/dm²/mo). Steels containing 2¼ and 5 percent chromium corroded at about 80 mg/dm²/mo. (auth).—NSA. 9249

4.7 Molten Metals and Fused Compounds

4.7, 6.2.2

Corrosion of Iron in Fused Salt Mixtures. V. P. Kochergin, A. V. Kabirov and O. N. Skornyakova. *J. Applied Chem. USSR* (Zhurnal Prikladnoi Khimii), **27,** No. 9, 945-952 (1954) Sept.

Causes of corrosion of Armco iron in fused carnallite at various temperatures (500-700 C) investigated. 8 tables; 2 figures, 12 references.—ATS. Translation available: Assoc. Tech. Services, Box 271, East Orange, New Jersey. 9168

4.7, 6.2.3, 6.2.5

Corrosion of Steel in Molten Salts and Alkali at 475 to 500° C. (In Polish). H. Jodko and M. Wiekiera. *Przemysl Chem.,* **10,** No. 12, 593-599 (1954) Dec.

Attack on carbon, stainless and chromium-aluminum-silicon-molybdenum steels by three common salt mixtures used as heat transfer media. Tables, photographs, graphs. 7 references.—BTR. 9120

4.7, 8.4.5

Construction Materials for Liquid Sodium Systems. E. G. Brush. *Corrosion,* **11,** No. 7, 299t-303t (1955) July.

The use of sodium as a heat transfer agent in nuclear power plants has resulted in a new phase of corrosion technology to evaluate the surface properties of materials of construction for high temperature, irradiated, liquid metal cooled heat transfer systems.

In pure sodium, engineering alloys may be subject to mass transport effects, preferential solution of alloying constituents and diffusion welding of mating surfaces. Trace amounts of impurities which are difficult to remove result in damaging oxidation and also act to accentuate preferential solution phenomena, particularly decarburization and intergranular attack.

The resistance of alloys to attack by sodium has been investigated in static and dynamic laboratory tests and in pilot plant heat transfer systems. Extensive laboratory data and service performance indicate that the design engineer has a wide selection of materials of construction that will give satisfactory service in high temperature sodium systems. 9109

5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2.1, 7.2, 8.4.3

How to Combat External Casing Corrosion. W. A. Johnson. *World Oil,* **139,** No. 4, 182, 184 (1954) Sept.

If so much as one ampere of current flows from the casing into the formation, about 20 pounds of steel are lost yearly. Two ways of handling this problem, by insulating flow lines and by cathodic protection are described.—INCO. 9112

5.2.3, 7.7

Carbon Anode Installed in Electric Cable Conduit. Howard L. Davis, Jr. *Corrosion,* **11,** No. 7, 295t-298t (1955) July.

A high ampere-year impressed anode consisting of graphite rods connected to an insulated header wire has been developed and installed by the Philadelphia Electric Company in its underground conduit system. The rods are two inches in diameter and 18 inches long. They are spaced five feet apart and pulled into a duct in lengths up to 500 feet. Special reels with flat sides are used to handle the anode. The first installation was in 6000 feet of conduit to protect lead sheathed power cables. Direct current is supplied to this anode by one rectifier located in the middle of the conduit run. Tests have indicated that protection has been obtained comparable to that available with continuous metal ribbon anodes, but life expectancy is considerably longer and troubles due to anode separation caused by uneven dissipation of ribbon type anodes is avoided. 9123

5.2.2

Sacrificial Anodes at Work. T. R. B. Watson. *Modern Metals,* **10,** 82-84 (1954) November.

A review of some applications for magnesium anodes in Canada. The cathodic protection of Union Gas Co.'s buried pipe lines is described. Magnesium is being used for the protection of large steel industrial hot water tanks. Cathodic protection is a routine specification for all ships of the Royal Canadian Navy, and is achieved mainly with magnesium anodes. Illustrations.—INCO. 8826

5.3 Metallic Coatings

5.3.4, 6.4.2

Nickel Plated Aluminum Sheet. J. H. James and H. Paige. *Product Eng.,* **25,** No. 12, 167-170 (1954) December.

Development of processes for depositing adherent, ductile and corrosion resisting nickel deposits on aluminum sheet, which can be heat treated and formed after plating. Two grades of aluminum were selected for testing:

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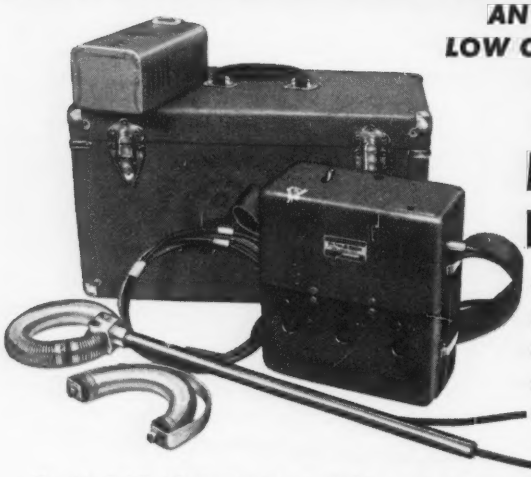

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Alclad 24s and 3s. Results of plating and mechanical tests indicate the properties of nickel plated aluminum alloys will permit its heat treatment and fabrication with but little deviation from standard procedures. With exception of applications involving extended exposure to salt atmospheres, corrosion-free service can be obtained by proper selection of aluminum alloy and plaing thickness. Compositions of nickel plating solutions are tabulated, as well as results of tensile strength, yield strength and elongation tests. Graphs and six references.—INCO. 8519

5.3.4

Addition of Surface-Active Agents to the Nickel-Plating Bath. Part I: Pin Holes on the Plated Nickel. Part II: Properties of the Baths. M. KIKUCHI AND K. OKI. *Repts. Govt. Chem. Ind. Res. Inst. Tokyo,* **49,** 65-68; 69-71 (1954); *Chem. Abs.,* **48,** 10455 (1954) September 25.

Part I. Sodium isopropylnaphthalenesulfonate (0.5-2g per liter) added to nickel baths at pH 4.9 and 5.9 ($NiSo_4 \cdot 7H_2O$ 250, $NiCl_2 \cdot 6H_2O$ 25, H_3BO_3 30 g per liter and $NiSO_4 \cdot 7H_2O$ 150, NH_4Cl 15, H_3BO_3 15 g per liter, respectively) lowered the surface tension most and produced fewest pin holes. Next best was polyethylene laurate, then Santomerse 1.

Part II. Above agents increased hydrogen overvoltage of baths, reduced contact angle (more so on nickel than on copper base) and lowered viscosity, electrodepositing nickel in finer grains with fewer pin holes on surface—INCO. 9143

5.3.4

Kanigen Nickel Plating. GREGOIRE GUTZEIT. *Metal Progress,* **66,** No. 1, 113-120, 146 (154) July.

The process described was developed from the reaction in which the oxidation of $Na(H_2PO_2)_2$ to $NaH(HPO_3)$ in the presence of a catalyst causes the reduction of nickel chloride and the deposition of nickel on the catalytic surface. The original process was expensive and slow and the solution deteriorated in use. The following conditions (covered by U. S. Patent No. 2,658,841) have been found to be optimum the ones: $[Ni^{+2}]/[H_2PO_2^-] = 0.25 - 0.60$; concentration of $(H_2PO_2^-) = 0.15\text{-}0.35$ mole; initial pH: $Na^+ = 4.6\text{-}5.5$, $Ca^{+2} = 5.0$; buffer concentration 0.120 mole; ratio of solution volume to catalytic area: 10:1. The addition of short-chain aliphatic dicarboxylic acids substantially increases the rate of deposition. Flow diagrams are given to illustrate the system of continuous circulation, filtration, and regeneration necessary to maintain the plating rate and quality in the presence of certain stabilizers. Characteristics of coatings are given.—MA. 9133

5.3.4

Electrodeposition of the Platinum Metals. E. H. LAISTER. Paper before Soc. Francaise de Met., Autumn Mtg., 1954. *Metal Industry,* **85,** Nos. 21, 23, 427-429, 469-470 (1954) November 19, December 3.

Processes and applications for plating of platinum, palladium and rhodium are discussed. Rhodium is most important from point of view of electrodeposition because it is little more than half the specific gravity of platinum, is whiter, harder and more chemically stable than other platinum metals and is easily electrodeposited. Platinum is plated in a

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sodium-hexahydroxy-platinate bath, while a solution of tetrammino-palladous nitrate is commonly used for palladium plating. Phosphate and sulfate solutions are in use at present for plating rhodium although sulfate solution is more desirable. Average operating conditions for each plating process are given. Uses are divided into three main groups—decorative, mechanical and electrical and chemical. A nickel undercoat is used for applications such as reflectors working at high temperatures. Properties of platinum metals are tabulated.—INCO. 9157

5.3.4

Chelating Agents in Electroplating. C. D. LEONARD. *Electroplating*, **7**, No. 10, 365, 367, 369-370 (1954) October.

Chelating agents used in electroplating are usually based on salts of ethylenediamine-tetra-acetic acid. Brief account of their chemistry; applications in electroplating (effect on pH of plating solution and in controlling impurities in plating solutions); copper immersion deposits; and analysis of plating solutions. —BNF. 9172

5.3.4, 8.8.3, 5.9.1, 1.6

Symposium on Electroplating and Metal Finishing Held (at the National Metallurgical Laboratory, Jamshedpur, India) on March 7 and 8, 1952. T. BANERJEE AND D. S. TANDON (Editors). Book, 1952, 177 pp. Obtainable from National Metallurgical Laboratory, Council of Scientific and Industrial Research, Jamshedpur, India.

Includes: Impact of Modern Science in Plating Industries with Special Reference to India, T. Banerjee; Some Basic Concepts on the Rate of Film Formation on Metals and Alloys, G. P. Chatterjee; Anodic and Cathodic Crystal Growth and Structures, A. Goswami; X-ray Structure of Electrodeposited Alloys, T. Banerjee; Phase Structure of Cast and Electrodeposited Alloys, V. M. I. Nambissan; Influence of Structure of Electrodeposits on the Brightness of Plated Surfaces, A. A. Krishnan; Addition Agents in Electroplating, S. D. Gokhale; Prevention of Corrosion of Metals by Protective Coatings, S. C. Shome; The Nature of the Electropolishing State, H. Lal; Influence of Surface Condition on the Fatigue of Metals, B. N. Das and M. S. Mitra; The Electrodeposition on Non-Conducting Surfaces, D. R. Dhingra, G. N. Gupta and M. G. Gupta; Plating Non-metals, K. Chakraborty and T. Banerjee; Thickness of Anodic Eilms on Aluminium, S. S. Bhatnagar and B. R. Nijhawan; Anodization and Multi-Colouring of Pure Aluminium, D. R. Dhingra, M. G. Gupta and M. C. Bhattacharya; Plating on Aluminium, D. S. Tandon and T. Banerjee; Electrodeposition—Its Importance and Necessity, A. K. Bhimani; Specifications in Plating, A. Goswami; Plating Materials: Their Availability in India, K. K. Majumdar; Electrodeposition of Silver from the Iodide Bath, T. L. Ramachar; Electrodeposition of Metals from Fluoborate Baths, J. Balachandra; Codeposition of Nickel and Chromium, V. M. Dokras; Industrial Brass-plating from Non-cyanide Bath, S. K. Roy and T. Banerjee; Efficiency and Economy in the Electrodeposition of Nickel, J. McNeil; Common Plating Troubles and Their Cures, R. U. Khan; Some Jari Plating Defects and Their Removal, T. Banerjee and B. L. Sen; Metal Surface Protective Coatings, P. K. Gupte and B. R. Nijhawan; Rust Proofing and Phosphatising Treatment of Metals, S. Hebel; Metal Finishing, M. Roy and T. Banerjee.—BNF. 7946

5.3.4

Effect of Impurities and Purification of Electroplating Solutions. Part. I. Nickel Solutions. Part 8. The Effects and Removal of Lead—Am. Electroplater's Soc. Research Project 5. D. T. EWING, J. K. WERNER, C. J. OWEN, W. O. DOW AND R. J. ROWE. Paper before AES, 41st Ann. Conv., July 15, 1954. *Plating*, **41**, No. 11, 1307-1311 (1954) November.

Effects of small amounts of lead present in four types of nickel plating solutions on appearance, adhesion, ductility, salt spray (fog) corrosion resistance, hardness and throwing power of nickel deposits were studied. Watts nickel solutions of pH 2.2 and 5.2, nickel-cobalt and organic nickel solutions were used. Tendency for all deposits to brighten occurs with increasing lead content. Adhesion was unchanged; ductility is not appreciably affected. Increasing lead concentration slightly increases corrosion resistance of heavier deposits. Removal of lead is effective using low current density electrolysis. Tables, graphs, 7 references.—INCO. 9267

5.3.4

Electrodeposition of Bismuth. K. B. MORRIS, D. Z. DOUGLASS AND C. B. VAUGHN. *J. Electrochem. Soc.*, **101**, No. 7, 343-347 (1954) July.

Deposition of high-purity bismuth from molten mixtures of bismuth trioxide, sodium chloride and calcium chloride with a tungsten cathode and carbon anode. Energy consumed in electrolysis is about 1 kWh/lb. bismuth.—BNF. 9266

5.3.4, 2.4.2

Equipment for the Study of Electrodeposition on Oxide-Soiled Surfaces. H. B. LINFORD AND D. O. FEDER. *Plating*, **4**, No. 10, 1183-1187 (1954) October.

All the work is carried out within a "dry" box filled with helium substantially free from moisture and oxygen. The box has three compartments: a vacuum furnace section for preparing clean, oxide-free specimens and for their controlled oxidation; a plating compartment and a microbalance. The equipment will be used in American Electroplaters' Society Research Project No. 12.—BNF. 9176

5.3.4, 3.5.9

Recommended Practices for Metallizing, Part III. Application of Metallized Coatings to Protect Against Heat Corrosion. 1955, 9 pp. American Welding Society, 33 W. 39th Street, New York 18. Per copy, 50c.

Heat corrosion is the subject of this third report in series titled "Recommended Practices for Metallizing." It provides an authoritative source of information dealing with application of metallizing to reduce heat corrosion for temperatures up to and over 1800 F. Equipment requirements and methods of surface preparation are listed in detail. Metallizing procedure including wire and sealer compositions and inspection tests are given as well as typical coatings for specific applications. 9229

5.3.4, 6.3.15, 6.3.20

Titanium and Zirconium Cladding. J. E. HUGHES. *Metal Treatment*, **21**, No. 108, 431-432, 430 (1954) Sept.

Strong ductile composites of titanium clad with copper, aluminum and Duralumin-type alloy were obtained by hot rolling. Zirconium similar though more difficult to clad with aluminum and its alloys. Possible uses.—BNF. 9144

5.4 Non-Metallic Coatings and Paints

5.4.5, 8.9.5, 1.3

Protective Coatings for Ships and Marine Installations. J. C. HUDSON. Paper before Soc. Chem. Ind., Glasgow, March 5, 1954. *Chemistry & Industry*, No. 23, 640-651 (1954) June 5.

A review of protective coatings used on steel in the shipping and allied industries. Under general factors influencing

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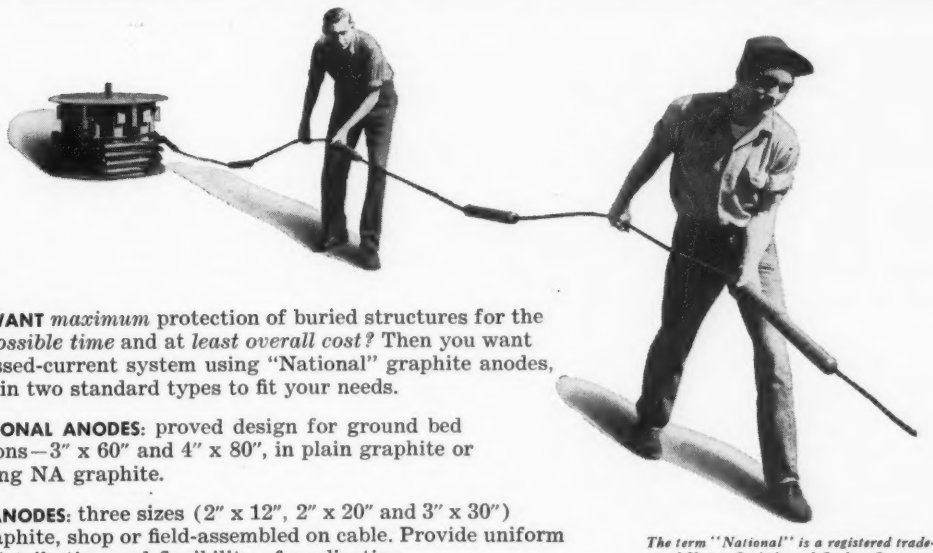

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protective coatings, basis steel, design, surface preparation of the steel and coating thickness are considered. Paints, metallic coatings, concrete, tar and bitumens and sodium-silicate base coatings are discussed. Protection of light-gauge steel and of heavy structural steel against atmospheric exposure, protection against sea water and protection against soil corrosion are presented with practical examples (steel piling, ships' hulls, rivets, etc.) and coating compositions.—INCO. 8471

5.4.5

Moisture Resistance of Paint Films. E. J. DUNN. *Official Digest Federation Paint and Varnish Production Clubs,* **26,** No. 353, 387-407 (1954).

The presence of moisture is the major cause of blistering, spotting, etc. Five factors concerned are permeability, sorption, swelling, film solubility and blistering. The results of tests were reported for various media and pigments and conclusions assessed in terms of number of coats and other variables. A film with high moisture resistance has 1) low thermal expansion, 2) average high permeability, 3) low water sorption, 4) low swelling, 5) high adhesion, 6) water-resistant pigment and vehicle. —EL. 9268

5.4.5

The Use of Melamine Resins in Organic Protective Coatings. I. GREENFIELD. *Product Finishing,* **7,** 61-68 (1954) Sept.

Melamine properties; production methods; formulation; advantages; application methods; uses. Photographs, structural formulas.—BTR. 9254

5.4.5

Reaction Primers in the Lacquering of Metals (In German). B. ELFISCH. *Werkstoffe u. Korrosion,* **5,** No. 2, 54-56 (1954) Feb.

Reaction- or wash-primers applied to metals combine with the underlying metal to form an insoluble metallo-organic coating, and with any paint applied above. This intergrowth of substrate metal and overlying paint passivates the metal by the production of phosphates and provides a satisfactory mechanical adherence of paint to metal. An American reaction-primer, prepared in accordance with Specification MIL-C-15328A, containing zinc chromate as a base, is suitable for application to clean metal and zinc sheets; a detailed account of its mode of application is given. The composition of the primers is determined by the metal to be protected. The mechanism of the protection is discussed. In Switzerland primers have been developed incorporating plastic materials based on polyvinylchloride having the nature of lacquers and drying to films of thickness 0.0075-0.00125 mm in 14 minutes, having no tendency to flake off.—ZDA. 9255

5.4.5, 6.4.2

Adhesion of Paint Coatings on Aluminum. K. BROOCKMANN. *Aluminum,* 30, 279-283 (1954); *Light Metals Bull.,* 16, No. 17, 743 (1954); *Farbe u. Lack,* 60, No. 10, 445-448 (1954).

An investigation of the influence of the medium on the adhesion of paint to aluminum is reported. Correlation occurs between stripping force and the thickness of the oxide film on the aluminum. Tables, 21 references.—RPI. 9212

5.4.6, 1.6

Steel Structures Painting Manual. Vol. II. Systems and Specifications. JOSEPH BIGOS, Editor. 1955, 292 pp. Steel Structures Painting Council, 4400 Fifth Avenue, Pittsburgh 13, Pennsylvania.

An attempt is made to itemize the types of corrosive environments against which coatings may be expected to protect steel, together with corresponding recommendations for surface preparation, priming and finish coats. The aim of the council is to provide sets of specifications which are so ramified that they may be used in varying combinations to secure protection under given conditions. These specifications need modification, the opening chapter of the book points out, to accommodate for special circumstances related to the exposure and the economics involved.

The book is divided into secions as follows, each of which is sub-divided into numerous specifications related to specife items pertaining to the painting problem: Surface preparation specifications, pretreatment specifications, paint application specifications, paint specifications and paint system specifications. The types of paint include all the conventional oleoresinous formulations and many new formulations involving synthetics.

An alphabetical subject index is included. 9231

5.7 Treatment of Medium

5.7.7, 4.4.6

Hydrocarbon Purifier Reduces Aviation-Gasoline Corrosiveness. F. L. RESEN. *Oil Gas J.,* **53,** No. 8, 120 (1954) June 28.

Southwestern Oil & Refining Co. has developed a hydrocarbon purifier for rendering aviation gasoline negative to the copper-dish corrosion tests. Hot avgas passes through a reactant aggregate which neutralizes corrosive contaminants in the stream, whereupon it is sent directly to storage. The treater is suitable for corrosion removal of light products generally. Process and apparatus are described.—INCO. 8878

5.7.6, 8.8.3, 4.6.13

Ion Exchange a Practical Tool in the Plating Room. R. J. KEATING. Graver Water Conditioning Co. *Metal Finishing,* **52,** No. 12, 52-55 (1954) December.

Ion exchangers used in plating operations for the treatment of water for plating room use, for purifying plating baths by removal of heavy metal contaminants and for treatment of rinse waters for

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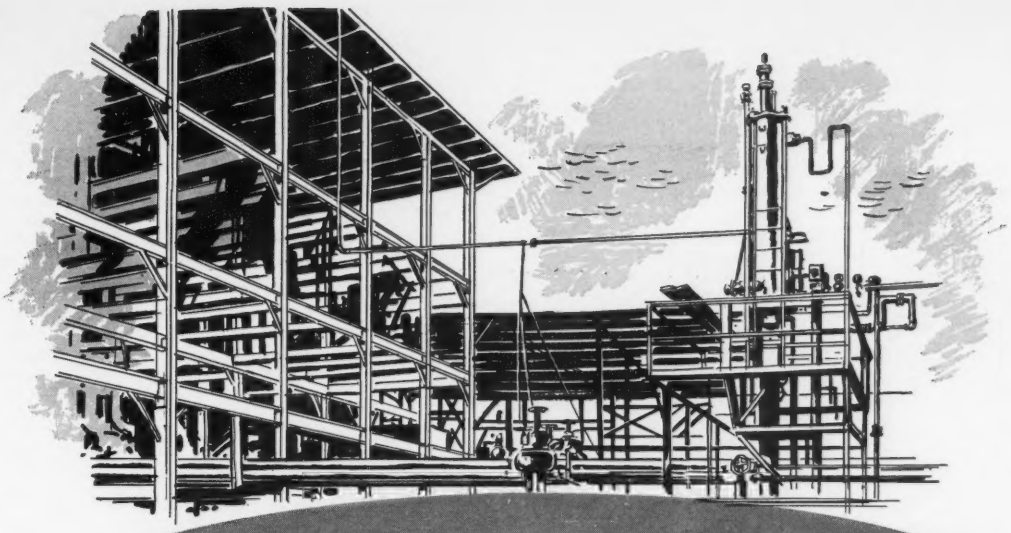

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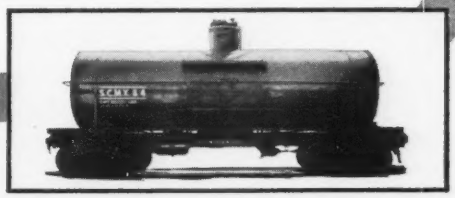

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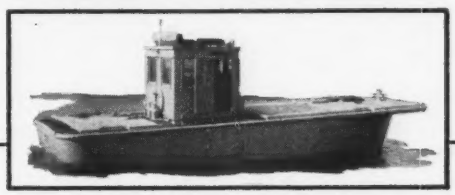

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valuable metal recovery and waste treatment. Discussion is confined to chromium plating solutions. Flow diagrams. —INCO. 9136

5.8 Inhibitors and Passivators

5.8.1, 1.7.1

Laboratory Development of Corrosion Inhibitors. Loyd W. Jones and Jack P. Barrett. *Corrosion,* **11,** No. 5, 217t-220t (1955) May.

The procedures used by a major oil company laboratory to develop a new series of corrosion inhibitors are presented. Initially developed to inhibit corrosion caused by combinations of air and hydrogen sulfide, the base chemical was found to be effective in laboratory tests with most other corrosive agents encountered in the oil producing industry. Several modifications of the base compound were made and have proved successful in the field. A review of the history of these inhibitors illustrates a pattern of development work which started by finding a material to solve a specific problem and expanded the solution to related problems. 9191

5.8.2, 4.6.2

Experiences With Filming Amines in Control of Condensate Line Corrosion. H. L. Kahler and J. K. Brown. *Combustion,* **25,** 55-58 (1954) January.

Includes photographs, diagram, tables. 4 references.—BTR. 9114

5.8.2, 8.4.3

How Corrosion Inhibitor Solved Refinery Fouling Problems. N. S. Banta and C. A. Murray. Pure Oil Co. *Oil & Gas J.,* **53,** 126 (1955) March 14.

The use of a demulsifying chemical in conjunction with a corrosion inhibitor showed immediate improvement following injection. The chemical was introduced into the stream ahead of the contact condenser on a continuous basis by means of a small proportioning pump. Excessive pressure drop and fouling were sufficiently reduced so unscheduled shutdowns to clean bundles were not necessary.—VISCO. 9228

5.8.3, 2.3.5

Use of the Pearson Bridge in Corrosion Inhibitor Evaluation. E. J. Simmons. *Corrosion,* **11,** No. 6, 255t-260t (1955) June.

The basic operation of the Pearson bridge, a circuit for measurement of electrode potentials of remote electrodes in the presence of current flow, is described. Data on the effect of impressed current on the potential of steel electrodes in various systems containing corrosion inhibitors are presented. Certain oil-soluble inhibitors appear to form a film on the metal surface which causes a high rate of change of electrode potential with change in impressed current. The semi-quantitative relationship of this change, called, for simplicity, a film resistance, is demonstrated. Adsorption and desorption rates can be determined from this relationship. Inhibitors which adsorb rapidly invariably give nearly 100 percent protection in weight loss tests, whereas inhibitors which adsorb more slowly show a percent protection which is dependent on the relationship between adsorption time and duration of test. Water-soluble organic inhibitors do not exhibit this type of film, which may actually be dependent on the oil phase itself for its formation. 9196

5.8.3, 3.8.3

Passive States Produced by Oxidizing Agents on Common and Special Steels. (In Italian.) A. Indelli. *Metallurgia italiana,* **46,** special supplement to No. 5, 34-35 (1954) May.

Study of action of chromates and nitrites on anodic and cathodic reactions. 14 references.—BTR. 9178

5.8.3, 4.3.2

Acid Corrosion Inhibition by High Molecular Weight Nitrogen-Containing Compounds. Raymond A. George and Norman Hackerman. *Corrosion,* **11,** No. 6, 249t-254t (1954) June.

The adsorption of various long chain amines, amine acetates, quaternary salts and ethylene oxide-octadecylamine condensates from benzene solution onto steel was determined. The acid dissolution of steel with previously adsorbed inhibitor and the dissolution of steel in aqueous inhibited acid solution were also studied. For the dodecyl compounds of each series, 1) adsorption for a di-amine can take place through both amine groups, 2) amine salts are not as effectively adsorbed as amines and 3) a high molecular weight quaternary salt is strongly adsorbed even though it has no available bonding electrons.

Inhibitor effectiveness for these compounds adsorbed from benzene solution onto steel are in decreasing order, 1) quaternary salt, 2) di-amine, 3) mono-amine, and 4) mono-amine acetate. In inhibited acid solutions, long chain amine acetates and quaternary salts furnish better than 90 per cent inhibition in the concentration range of 3.75 to 15×10^{-4} molar. Ethylene oxide and octadecylamine condensation products were less effective in this concentration range, providing approximately 85 per cent inhibition. However, they were more effective than the amine acetates and quaternary salts where less than 3.75×10^{-4} M. 9195

5.8.3, 4.3.2

Corrosion Inhibitors of Steel in Sulfuric and Hydrochloric Acid. (In Polish). H. Jodko. *Przemysl Chem.,* **10,** No. 2, 75-80 (1954) Feb.

Investigates thiourea, dibenzene sulfoxide, Tardiol F and urotropine. Tables. 2 references.—BTR. 9188

5.9 Surface Treatment

5.9.2, 8.9.5

A Practical Method for Cleaning and Descaling Cargo Tanks Contaminated with Black Oil Residues. J. F. Mills, F. E. Cook and H. S. Preiser. *J. Am. Soc. Naval Engrs.,* **67,** No. 1, 199-207 (1955) Feb.; *Corrosion,* **11,** No. 5, 200t-204t (1955) May.

A method for removing black oil residues from tanks is described. The cycle of operations includes ventilation of the tank, removal of existing sludge, steaming at 100 psi until temperature reaches 175-180 F, injection of an emulsion cleaner through a specially prepared jet, injection of cold water, cooling of the tank and washing down with high pressure jets of fresh water. The injector used is described and formula for emulsion cleaner given. Electrolytic descaling is effected by making the inner tank walls the cathode in an electrical circuit moving through a suitable aqueous electrolyte filling the tanks. 9110

5.9.3, 3.7.3

Some Recent Developments in Vapour Blasting. British Vapour Blast Ltd. *Machinery,* **85,** 11-19 (1954) July 2.

Describes plant produced by this firm. Applications (cleaning and finishing die-casting dies and steel moulds for plastics, treating the edges of high-speed steel cutting tools, finishing engine cylinder bores); effect of treatment in extending fatigue life; use prior to plating and in Capri honing process; treatment of propeller blades.—BNF. 8588

5.9.4, 6.2.2

A Radiometric Study of the Iron Phosphating Process. S. L. Eisler and J. Doss. *Metal Finishing,* **52,** No. 3, 60-63 (1954) March.

Summary of results of radiometric tests made on composition and effectiveness of phosphate coatings on iron. 9256

5.9.4, 2.3.9

The Electrolytic Polishing of Metals: Basic Principles and Applications of Electrolytic Polishing in Science and Technology. P. A. Jacquet. *Metall,* **8,** No. 11/12, 449-458 (1954).

An illustrated review of the following aspects of electrolytic polishing 1) its historical development; 2) the characteristics—topography, structure, and chemical properties—of metal surfaces in relation to the effects of working, heat-treatment and subsequent mechanical polishing before electropolishing; 3) the surface conditions and properties of metal surfaces; 4) its basic principles and the usual conditions under which it is carried out; 5) the characteristics of the finished surfaces; 6) its scientific applications—in the investigation of the structure, physical properties and physico-chemical properties of metals and alloys; and 7) its industrial applications

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—and advantages over mechanical polishing. 69 references (many collective). —MA. 9199

5.9.4, 6.3.19, 6.4.1

Surface Treatments for Pressure Die Castings. (In French). R. GRUNBERG. *Metallurgie*, **86**, No. 5, 395, 397, 399 (1954) May.

A review of the finishing treatments applied to zinc and light alloy die castings to improve corrosion resistance and appearance, or to give the surface special electrical or mechanical properties. Chromating is described, the results of corrosion tests on passivated surfaces being quoted. Reference is made to the necessity of mechanical or chemical pretreatment before painting. The danger of lead contamination when remelting enamelled or varnished castings is pointed out.—ZDA. 9235

5.9.4, 6.4.2

The Sanford Process. A Method for Developing a Wear and Corrosion Resistant Surface on Aluminum Alloys. JOHN B. FRANKLIN. *Metal Treating*, **5**, No. 6, 2-3 (1954) November-December.

A new electrochemical process gives aluminum products sufficient hardness so that they may be substituted for steel where extreme wear resistance is required. In addition, it permits the use of aluminum alone in electrical and electronic components which require considerable dielectric strength. The process differs from conventional anodizing methods in that oxide coatings thick enough to be of practical value are built up. Coating thickness is readily controlled by varying the treating time, e.g., in 10 min. an 0.0005-in. coating, in 55 min. an 0.0060-inch coating can be produced.

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5.9.4, 6.4.2

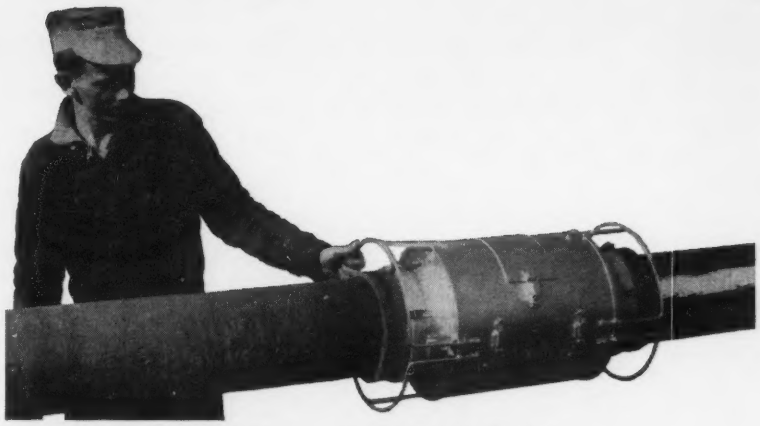
Treatment of Aluminium and Its Alloys in a Chromic Acid Bath at Alternating Current — Formation of "Black Coatings." (In Italian). L. GUERRESCHI. *Alluminio*, **23**, No. 5, 515-532 (1954) October.

The conditions have been studied for the formation of a bright black deposit of considerable adherence, increased hardness and excellent corrosion resistance which is obtained by anodic oxidation of aluminum sheet in a 3 per cent chromic acid bath. However, the electrochemical conditions do not seem to be sufficient for preparing these deposits commercially on a large scale. The current efficiency is below the theoretical efficiency due to partial reversibility of the reaction or to deposition of metallic chromium. Initial polarization of the electrodes seems to have a favorable influence.—ALL. 9245

5.9.4, 6.4.2

Study of the Conditions of Growth of Anodic Aluminium Oxide Films. J. HERENGUEL AND P. LELONG. *Rev. Met.*, **51**, No. 6, 411-417; disc., 418 (1954).

Herenguel and Lelong investigated the effect of various factors on the growth of oxide films in the anodic oxi-



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dation of aluminum. In particular they measured the thickness (b), of the metal transformed to oxide and the increase in thickness (a) due to the formation of oxide. The actual rate of oxidation is given by b divided by the time of treatment, the relative volume increase is given by $g\ (\%) = \frac{a}{b} \times 100$. The present investigation, unlike preceding ones, distinguished between a and b, which were measured by means of interference fringes. Many difficulties in applying this method had to be overcome. The method is non-destructive and very accurate, though it has certain limitations. The metals used were 99.99% aluminum and Brillalumag 3 (aluminum-3% magnesium). The electrolyte was 180 g/1 sulfuric acid at 20 C. The principal findings were: 1) the curve of g against the current density showed that the former rose rapidly at low current density and then became steady. 2) for a given current density, g is independent of the quantity of metal oxidized. This is in apparent contradiction to Elssner's results [*Aluminium*, **25**, 310 (1943)] in whose experiments, however, a considerable degree of re-solution took place. 3) No appreciable variation of g as a function of the crystal orientation was observed. 4) The use of oxalic acid instead of sulfuric acid indicated that the nature of the electrolyte has probably some small effect on g. 5) No difference of g was observed in pure aluminum and Brillalumag. Measurements of the refractive index, using the wave-length of the sodium doublet, showed that under all conditions the index was 1.58, varying from 1.54 to 1.63 (on 30 measurements). All these determinations serve to contribute to a more precise knowledge of the kinetics of the growth of anodic oxidation films and also of their genesis. 9 references.—MA. 9206

5.9.4, 6.4.2

Protective Anodizing of Highly Reflective Aluminium. YASUYUKI KIMURA, TOSHIRO FUKUSHIMA AND SAKAE TAJIMA. *Light Metals* (Japan), No. 12, 70-73 (1954) Aug. 31.

Chemically polished 1S and 2S-aluminum specimens were anodized in various concentrations of oxalic, sulfuric, sulfamic, phosphoric and chromic acid and sodium bisulfate, sodium carbonate, by applying direct current at 1.0 amp./sq. dm. at 25 C. Variations of reflectivity of polished surfaces and anodized surfaces were determined as well as abrasion and corrosion resistance. The effect of current density was studied with the two typical baths, 10 vol.-% sulfuric acid, 5 wt.-% oxalic acid. Decrease of reflectivity with anodizing time was measured by both DC and AC using 1S and 2S which were polished chemically or electrolytically.—ALL. 9147

5.9.4, 6.4.2

1) Determination of Barrier Layer Thickness of Anodic (Aluminium) Oxide Coatings. 2) Factors Affecting the Formation of Anodic (Aluminium) Oxide Coatings. M. S. HUNTER AND P. FOWLE. 1) *J. Electrochem. Soc.*, **101**, No. 9, 481-485 (1954) Sept.; 2) *ibid.*, **101**, No. 10, 514-519 (1954) October.

1) The specimen is made the anode in an electrolyte that does not exert significant solvent action on the oxide and current readings are made at increasing voltages, using the circuit given. Applications of the method are described. 2) Effect of electrolyte composition and operating conditions on the formation of porous-type coatings on aluminum. Conditions existing at the bases of pores are quite different from those in the body of the electrolyte.—BNF. 9181

5.9.4, 6.4.2, 5.3.2

Motor Industry Finds an Alternative to Chromium Plate in Chemical Polished Aluminum. R. PINNER. *Plating & Metal Finishing*, **8**, No. 1, 4-8 (1955) January.

With the simultaneous development of chemical polishing processes and of aluminum alloys specially formulated to respond to such processes, industry is offered an alternative which, in many cases cannot be distinguished from chromium plate but is cheaper to produce, retains its appearance better on outdoor exposure, does not rust and requires no nickel. Maximum advantage from the use of chemical polished aluminum is obtained on wrought materials. Chemical polishing process, electropolishing and applications are covered. Graph shows the influence of atmospheric exposure on the reflectivity of electro-brightened aluminum, chromium plate, nickel plate and others. Graphs, tables and 10 references.—INCO. 9219

5.9.4, 6.4.4

Anodic Formation of Coatings on Magnesium, Zinc, and Cadmium. Disc. of paper of KURT HUBER by H. J. WRIGHT. *J. Electrochem. Soc.*, **101**, No. 6, 334 (1954) June.

Mr. Wright asks what the composition of some of the anodically formed coatings on magnesium are, how these are affected

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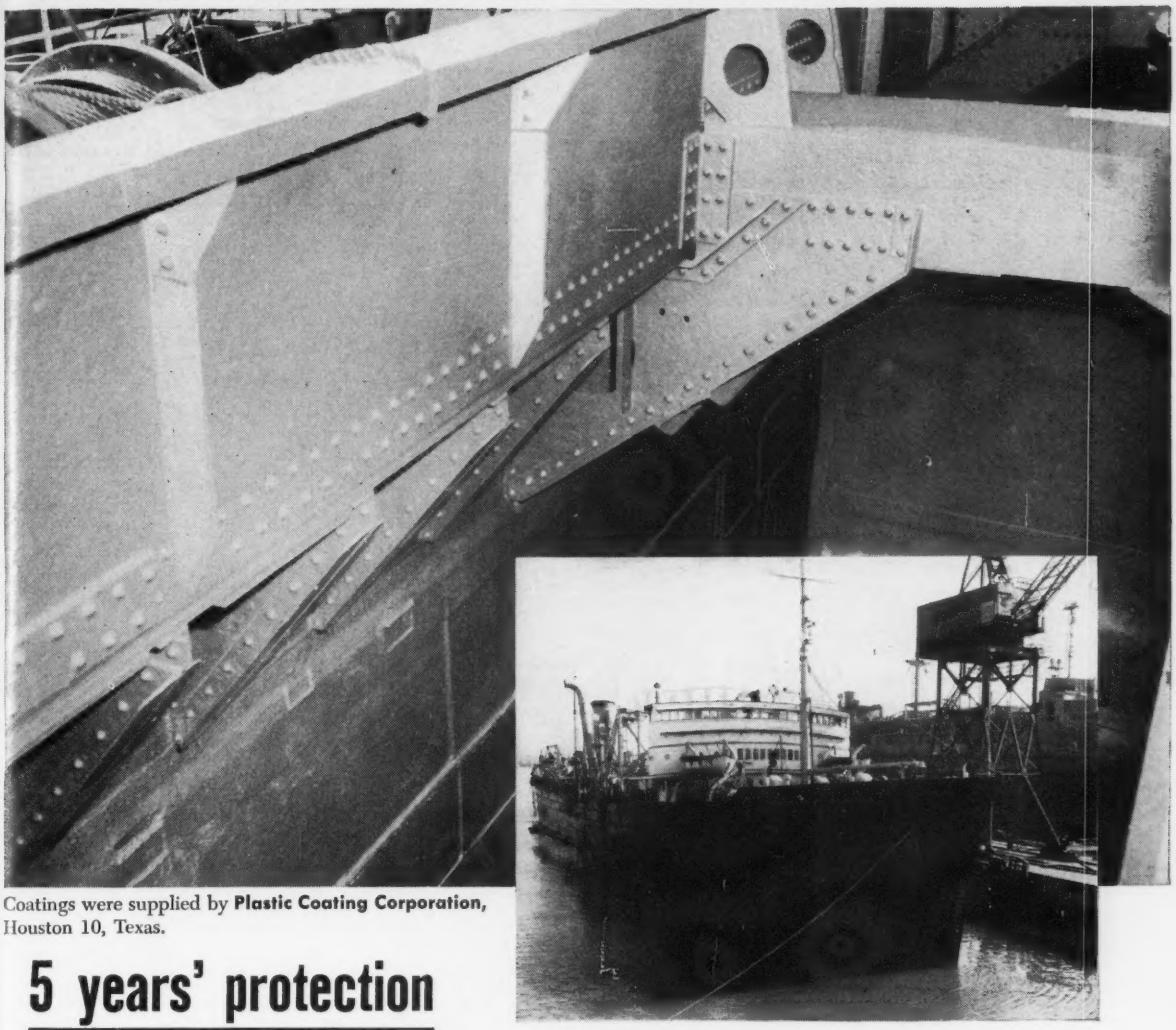

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by traces of chlorides, phosphates and sulfides and finally whether the metal oxides on magnesium are resistant to polyphosphates, etc., under anodic conditions. In reply the author states that the anodic behavior of magnesium was studied in solutions prepared with purest sodium hydroxide and no traces of chlorides, phosphates and sulfides were present; however, Fluckiger investigated the anodic formation of coatings on magnesium in aqueous solutions of ammonium fluoride and sodium tribasic orthophosphate. In 4N sodium tribasic orthophosphate coatings were formed in which magnesium oxide, magnesium hydroxide and occasionally magnesium orthophosphate could be detected. Magnesium oxide predominated, particularly with short formation periods (1 min. at 10-40 volts), while magnesium hydroxide became the principal component after longer formation periods. In an analogous manner, magnesium oxide, magnesium hydroxide and magnesium fluoride were formed in 2N ammonium fluoride solution. And thus it appears that magnesium oxide is produced as the primary product, and subsequently it is hydrated or converted to an insoluble salt.—ALL. 9129

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6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.2, 3.2.2, 3.5.9

Oxidation of Iron in Air at High Temperatures. (In Russian). V. V. Ipat'ev and V. I. Tikhomirov. *Doklady Akademii Nauk SSSR*, **94**, No. 3, 505-508 (1954) January 21.

Rate of oxidation, composition and structure of scale produced during oxidation of Armco iron at high temperatures in dry and moist atmospheres. Diagrams, graphs, photograph. 14 references.—BTR. 9148

6.2.2, 3.5.9

Cast Irons in High Temperature Service. Richard J. Greene and Frederick G. Sefing. *Corrosion*, **11**, No. 7, 315t-32t (1955) July.

Cast irons in grate bars and furnace doors traditionally have been compared principally on their comparative growth properties. Recently, in an attempt to accumulate experimental data which might be more useful in predicting the serviceability of cast irons at elevated temperatures, tests have been conducted measuring the oxidation resistance of some of these materials. These tests are described in this article, with results on plain and low alloyed cast irons and highly alloyed austenitic cast irons in several environments. Some description of how cast iron deteriorates with growth is also included. The various typical applications of simple cast irons, low alloyed cast irons, austenitic cast irons and the ductile varieties of austenitic cast irons are described here with the engineering reasons for their economical use in high temperature service. 9189

6.2.2

Pearlitic Malleable Iron Stakes Claims to New Jobs for Castings. C. F. Joseph. Paper before Society of Automotive Engineers Mtg., Detroit, January 11, 1954. *SAE J.*, **62**, No. 10, 71-74 (1954) October.

Pearlitic malleable castings are replacing forgings, stampings and weldments in the automotive, refrigeration and allied industries. Advantages of pearlitic malleable (Arma Steel), including good wear resistance, excellent finishing quality, high yield strength and reduced machining time are covered. Present SAE mechanical property requirements for pearlitic malleable iron castings are tabulated. Except for the heat treatment cycle of the white iron, production of pearlitic malleable is carried out in the same manner as malleable iron. Tables.—INCO. 8554

6.2.2, 3.8.3

Passivity of Iron in Concentrated Sulfuric Acid. V. M. Novakovskii and A. I. Levin. *Doklady Akad Nauk SSSR*, **94**, No. 6, 1113-1116 (1954) Feb. 21.

Formula determines corrosion rate during oxidation of clean iron and corrosion of iron covered by ferric sulfate. Graphs. 6 references.—BTR. 8618

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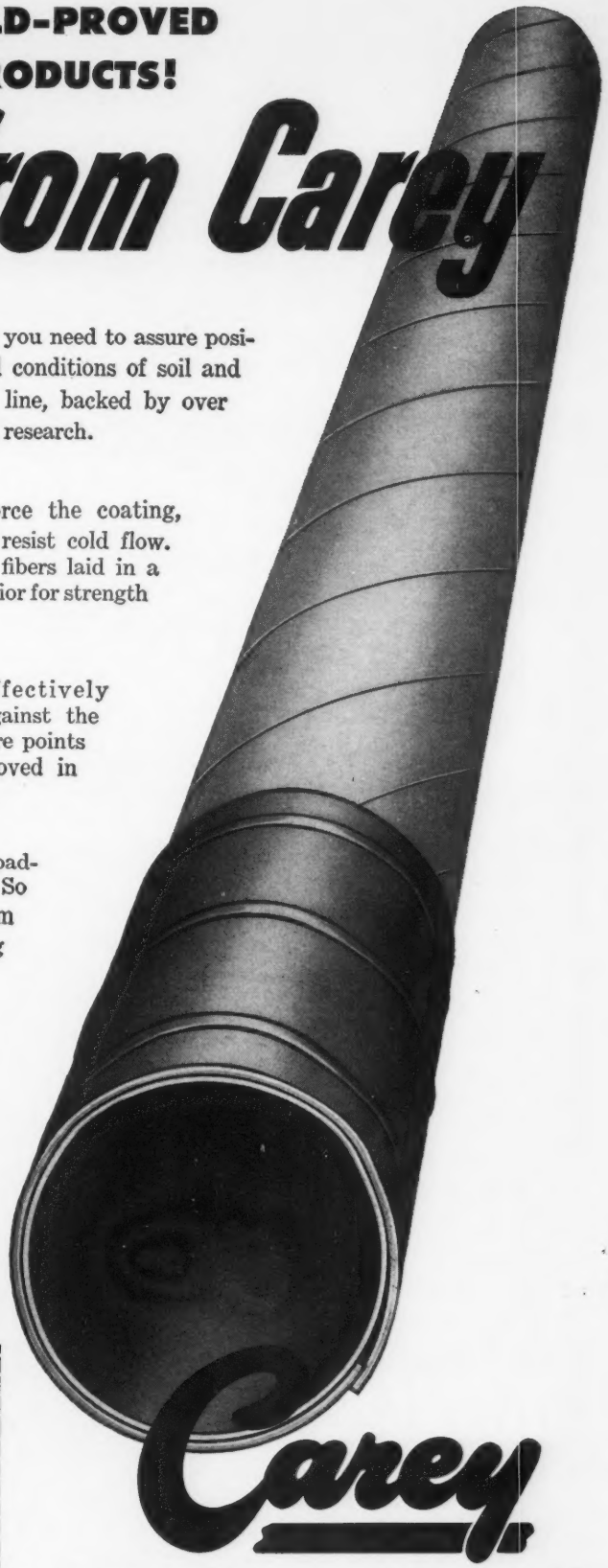

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6.2.2

Corrosion and Cathodic Protection of Iron: Experimental Demonstration. (In French). J. VAN MUYLDER AND M. POURBAIX. Cebelcor Tech. Rep. No. 11, April, 1954, 3 pp. Issued by Centre Belge d'Etude de la Corrosion, 21 Rue des Drapiers, Brussels.

The experiment described illustrates the corrosion of iron in a 0.1M sodium acid carbonate solution and the conditions under which an iron cathode corrodes or is passive in the same solution.—BNF. 8812

6.2.2

Elevated Temperature Properties of Ductile Cast Irons. C. R. WILKS, N. A. MATTHEWS AND R. W. KRAFT, JR. Amer. Brake Shoe Co. Paper before Am. Soc. Metals, 36th Ann. Conv., Chicago, November 1-5, 1954. ASM Preprint No. 34, 1954, 21 pp.

Creep and stress rupture properties are presented for three types of ductile cast iron from 800-1200 F: the familiar standard ferritic (containing 1.0% nickel) and pearlitic (1.0% nickel) grades and high alloy austenitic (22.0% nickel) type. Tensile properties at room and elevated temperatures are included along with growth tests. Barkedly higher hot strength at 1000 F was found in the alloy containing 22% nickel. Photomicrographs, tables, graphs and 7 references.—INCO. 8825

6.2.2, 3.2.3

Oxidation of Iron at 175 to 350 C. D. E. DAVIES, U. R. EVANS AND J. N. AGAR. *Proc. Roy. Soc., Ser. A,* **225,** No. 1163, 443-462 (1954) Sept. 22.

Oxidation of iron, previously freed from oxide by hydrogen treatment, was studied at 175 to 350 C. Five methods (gravimetric, electrometric, filmtransfer followed by chemical or microscopic examination, X-rays, and electron diffraction) were used to identify and estimate the different oxides. On hydrogen-reduced iron powder, ferrous oxide, magnetite and alpha-ferric oxide appear when oxygen is admitted, but the oxidation is not isothermal, since a glow appears on admission of oxygen even when the initial temperature is only 40 C. On hydrogen-reduced Swedish sheet, alpha-ferric oxide alone appears at 175 and 225 C, while at 300, 325 and 350 C a duplex film of magnetite (not gamma-ferric oxide) overlaid with alpha-ferric oxide is formed; at 250 C, the film consists of a single layer (alpha-ferric oxide) for 8 hours, but then magnetite appears below it at certain places and spreads laterally, the rate of magnetite formation increasing rapidly with time.—INCO. 8925

6.2.2, 3.2.3, 3.4.6, 3.4.9

Oxidation of Iron in Water Vapor, Vapor-Hydrogen, and Vapor-Oxygen Mixtures at High Temperatures. (In Russian). V. I. TIKHOMIROV, V. V. IPAT'EV, AND I. A. GOFMAN. *Doklady Akad. Nauk SSSR,* **95,** No. 2, 305-308 (1954) March 11.

Theoretical investigation closely corresponds to experimental results. Tables, graphs.—BTR. 8706

6.2.2, 3.5.9, 1.7.1

Properties of Cast Iron at Elevated Temperatures. J. R. KATTUS. Southern Research Inst. *Foundry,* **83,** No. 2, 96-97, 230-232, 234, 237 (1955) Feb.

Progress report on study to determine the load-carrying ability of cast iron at 700-1000 F. Work is being carried on under sponsorship of Joint ASTM-ASME Comm. on Effects of Temperature on Properties of Metals. Three phases of experimental work are planned. First phase consists of literature survey and screening tests on a number of samples, which is intended to show the cast irons with most promising high temperature properties for subsequent evaluation. Stress-rupture and creep tests will be run in second phase on most promising materials from first, and third phase will include thermal shock tests. Literature survey covers growth inhibitors, creep and growth tests and thermal shock data. Specimens include unalloyed, alloyed (containing 0.10-1.41% nickel), and nodular (containing 0.01% nickel and 0.07% magnesium) irons. Graphs and tables.—INCO. 8763

6.2.2, 3.7.2, 3.5.9

How the Addition of Metals Affects Sulphurization-Resistant Property of Cast Iron at High Temperature. (In English). M. SHIOZAWA AND H. NAKAI. Repts. Casting Res. Lab., Waseda Univ., No. 5, 11-13 (1954).

In a series of experiments conducted as to how aluminum, manganese, molybdenum and silicon added individually to cast iron affect sulfurization-resistant property at high temperature, aluminum was superior to all others, which followed successively in order of molybdenum, silicon and manganese. Qualitative spectroanalysis was conducted on the sulfurized layer and qualitative inquiries were made. Graph and tables.—INCO. 9072

6.2.5

New Stainless Alloy Bridges Gap Between 300 and 400 Series. A. J. LENA. Allegheny Ludlum Steel Corp. *Iron Age,* **174,** No. 23, 113-116 (1954) Dec. 2.

New type of stainless steel, AM350, is

essentially austenitic in the annealed state with good ductility, but, unlike 300 series, it can be hardened by heat treatment or by sub-zero cooling. Sub-zero hardening is preferred because of superior hardness, strength, ductility, impact strength and corrosion resistance. Tables give data on tensile properties and bend ductility, impact strength on basis of Charpy V notch test, short time high temperature tensile properties, effect of cold rolling and aging, and corrosion in various media. Nominal composition is 17.0% chromium, 4.2% nickel, 2.75% molybdenum, 0.6% manganese, 0.4% silicon and 0.08% carbon.—INCO. 8449

6.2.5

AM-350 . . . A New Type of Stainless Steel. A. J. LENA AND J. S. THORPE. *Steel Horizons,* **17,** No. 1, 14-17, (1955).

Hardening by subjection to —80 to —100 F temperatures increases the corrosion resistance of Allegheny Metal 350 stainless steels. The alloy has resistance comparable to Type 316 stainless and superior to that of Type 304 in boiling glacial acetic acid and 1 per cent sulfuric acid at 100 F. Maximum resistance to attack by boiling 65 percent nitric acid is obtained in the sub-zero cooled condition without tempering. Nitric acid rates are greater than those of Type 304 but less than those of other hardenable stainless steels such as Type 410.

Resistance of AM-350 to pitting type attack in 20 percent sodium chloride salt spray test is excellent.

The alloy may be hardened also by a double ageing process involving precipitation hardening heat treatment of 1300-1400 F for one or two hours and 800-900 F for one or two hours. Chromium carbides precipitate in the cooling interval between heats, altering the austenite so it transforms to martensite. Corrosion resistance in the double aged condition is not as good generally as in the sub-zero condition.

Extensive use for the metal in the aircraft industry is visualized. 8623

6.2.5

Effect of Design, Fabrication and Installation on the Performance of Stainless Steel Equipment. JAMES A. COLLINS. *Corrosion,* **11,** No. 1, 27-34 (1955) Jan.

Case histories are presented of failure in austenitic type stainless steel chemical process equipment, the recurrence of which have been prevented by improved design, better fabrication or installation. Thermal fatigue, concentration cell corrosion and stress corrosion cracking failures are considered. 8434

6.2.5

Improved Process Control Assures Economical Production of Extra Low Carbon Cast Stainless. R. W. DEWEESE. Electric Steel Foundry. *Iron Age,* **174,** No. 16, 133-135 (1954) October 14.

Method of producing extra low carbon (0.03% max.) 18-8 and 18-8 Mo stainless steels developed by Elec. Steel Foundry Co. involves careful selection of scrap, extra care in melting and cleaning operations and control of slag basicity. Control of carbon content is less difficult to maintain in arc furnaces than in induction furnaces although both are used. Low carbon content minimizes problem of carbon precipitation where service conditions do not exceed 800 F, thus decreasing corrosion rate. Numerous test specimens were machined to determine typical chemical composition and physical properties for 18-8 and 18-8 Mo. Corrosion rates of 12 random heats of ESCO 40L (18-8) alloy ranged far below that allowable under HW-5301 specifications. Tables.—INCO. 8463

6.2.5

Lower-Nickel Stainless Steel Castings. J. LOMAS. *Machinery Lloyd* (Overseas Edit.), **26,** 83, 85 (1954) Sept. 25; (European Edit.), **26,** 67, 69 (1954) Oct. 16.

In view of nickel shortage, renewed attention is being paid to 21-9 chromium-nickel cast steels as possible replacements for 26-12 chromium-nickel cast steels. Room-temperature strengths compare favorably, while the lower nickel steel castings have superior creep strength up to 870 C. When casting is to withstand thermal stress, lower strength material with high ductility is preferred to one with high creep strength but lower plasticity. High oxidation-resistance of the 21-9 steel castings up to 870 C, except in high-moisture air is noted. Complete oxidation in flue-gas atmosphere was observed at 1060 C. The 21-9 steel casting is non-magnetic, readily welded and machined. Application is mainly confined to temperatures between 650-870 C, but does not replace ferritic steel and heat-resisting cast irons up to 650 C. Lower nickel steel has higher ductility at 760 C than the 26-12 steel and does not undergo carbide precipitation.—INCO. 9145

6.2.5, 3.7.3

Microstructure of 18-8 Stainless Steels. The Relation with Electrolytic Polishing. Intergranular Sensitivity and Passivation. P. A. JACQUET. *Rev. Nickel,* **20,** No. 1, 1-16 (1954) January-March.

Results of electrolytic polishing in solutions of AcOH-$HClO_4$, Marble's reagent (cupric sulfate-hydrochloric acid),

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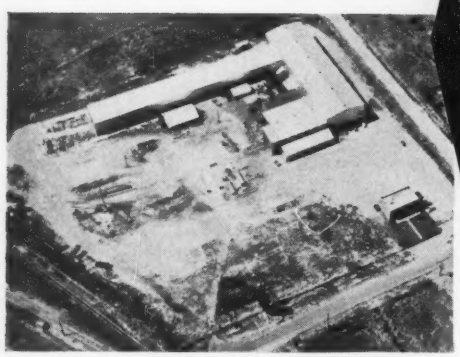

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oxalic acid, sodium cyanide and sulfuric acid-sodium dichromate are described to disclose structural differences resulting from thermal treatment. Photomicrographs show fully and partially austenitic structures, grain size, intergranular carbide precipitation, non-metallic inclusions and sensitivity to corrosion resulting from C_6Cr_{23} precipitation.—EL. 9140

6.2.5, 5.2.1

On the Cathodic Protection of Metals. Part II. On the Cathodic Protection of 18-8 Stainless Steel. (In Japanese). G. Ito. *J. Japan Inst. Metals,* **18,** No. 6, 338-341 (1954) June.

Effect of cathodic current on the corrosion of 18-8 stainless steel in various acid and salt solutions was studied. It was found that 18-8 stainless steel suffers cathodic corrosion at certain current densities in dilute hydrochloric acid, nitric acid, sulfuric acid and sodium chloride solutions, but this corrosion can be protected by higher cathodic current. This cathodic corrosion is due to the breakdown of protective oxide film on 18-8 stainless steel by hydrogen evolved on the cathodic surface by electrolysis of the solutions, but such active stainless steel can be protected by a higher cathodic current. This mechanism is schematically illustrated.—JSPS. 9103

6.2.5, 5.2.1

On the Cathodic Protection of Metals. Part III. On the Cathodic Protection of 13% Chromium Stainless Steel. (In Japanese). G. Ito. *J. Japan Inst. Metals,* **18,** No. 7, 390-392 (1954) July.

Cathodic protection of 13 percent chromium stainless steel was studied. In dilute hydrochloric acid and sulfuric acid solutions, 13 percent chromium stainless steel suffers somewhat from cathodic corrosion and it can be fairly protected by cathodic current. But in dilute nitric acid solution, cathodic corrosion occurs as described in the previous paper for 18-8 stainless steel. The conclusions of the 2nd and the 3rd reports are as follows: 1) The cause of cathodic corrosion of 13 percent chromium and 18-8 stainless steels is due to reduction of the protective oxide film on their surfaces. 2) In the case when the surface film gives good corrosion resistance to the alloys, cathodic current is of no use. But in the case when free corrosion is of a certain value, cathodic protection is effective in suppressing its occurrence.—JSPS. 9104

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.10, 3.2.3, 3.5.9

The Selective Oxidation of Nickel-Chromium Alloys at High Temperatures. J. Moreau and J. Benard. Paper before Inst. of Metals and Soc. Francaise de mét., Joint Spring Mtg., London, April, 1954. *J. Inst. Metals,* **83,** Pt. 3, 87-93 (1954) Nov.

The mechanism of selective oxidation of a nickel-4.6% chromium alloy has been studied between 800 and 1250 C using mixtures of hydrogen and water vapor as oxidizing agent. The morphology of the oxide formed on the surface of the alloy differs markedly from the surface structure of the unoxidized metal. Nucleation of chromic oxide is followed by its coalescence; at a later stage the primary oxide evaporates and the bare metal takes on a striated appearance. Various aspects of the observations are discussed, in particular the surface striations. In an oxidizing atmosphere, the surface of the specimen may be considered not as a

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Seated, Front Row: Alvan Richey, Hugh Wilbanks (Corpus Christi), Jack Davis, Bethel Bond, Gordon Doremus, Hank Hughes

Annual gathering for Engineering Conference held here recently by the personnel of the Cathodic Protection Service. Photo was taken in the conference room at the home office in Houston. The meeting represented more than 150 years engineering experience in cathodic protection.

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free-metal/atmosphere boundary, but as a metal/oxide interface. Selective oxidation of the chromium contributes to the building-up of this surface oxide film; when the temperature is sufficiently high the lattice of the metal beneath undergoes a reorganization, as a result of which the metal surface is enabled to adopt the micro-profile corresponding to its state of minimum free energy.—MA. 8583

6.3.11

The Significance of Precious Metals in Modern Developments of Materials. K. RUTHARDT. Hanau. *Metall*, **8**, 591-596 (1954) Aug.

Properties and industrial applications of silver, gold, palladium, platinum, rhodium, iridium, ruthenium, osmium and their alloys. Particular reference is made to use as electrical contact materials (platinum-nickel, palladium-copper, gold-nickel, silver-palladium-copper, platinum-tungsten, platinum-copper, palladium-tungsten), in chemical industry (spinnerets, apparatus, anodes), dental materials, jewelry and ball-point pens.—INCO. 8640

6.3.11, 3.4.8

The Reaction of Silver-Palladium Alloys with Sulphur at Elevated Temperatures. E. RAUB, B. WULLHORST AND W. PLATE. *Z. Metallkunde*, **45**, 533-537 (1954) Sept.

Review of related literature dealing with attack of sulfur on palladium-silver alloys, followed by results of thermoanalytic, microscopic and X-ray investigations of silver-palladium-sulfur system. Reasons for attack of sulfur on palladium-silver dental alloys, with notes on causes of damage by sulfur noted by dentists on gold-plated palladium-silver alloys are given.—INCO. 8728

6.3.11, 3.7.2, 3.5.9, 7.7

Platinum Metals in New Laboratory Equipment. H. SPEIDEL. Heraeus. *Metall*, **8**, 599-600 (1954) August.

Loss of hardness of pure platinum after heating at 1200 C makes it unsuitable for certain laboratory equipment. Unsuitability of other precious metal alloying additives to platinum is discussed. Considerable improvement is afforded by preparing platinum sheet from sintered platinum to which chromium oxide (0.03%) and zirconium oxide (0.015%) have been added. Slight disadvantage of such material vis-a-vis pure platinum to attack of reducing atmospheres and use of pure rhodium strip for electrical heating elements withstanding more than 1000 hr. at 1600 F and repeated heating to 1800 C are discussed.—INCO. 8717

6.3.13, 3.2.3, 3.8.4

High Pressure Oxidation of Metals: Tantalum in Oxygen. R. C. PETERSON, W. M. FASSELL, JR. AND M. E. WADSWORTH. *J. Metals (Trans. AIME)*, **6**, No. 9, Section 2, 1038-1044 (1954) Sept.

Temperature and pressure dependence of the reaction of tantalum in oxygen were investigated at 500-1000 C and 10 mm. Hg to 600 psi total oxygen pressure. Photograph, diagrams, graphs, tables, 13 references.—BNF. 8600

6.3.15

Surface-Hardening Processes for Titanium and Its Alloys. R. W. HANZEL. *Metal Progress*, **65**, No. 3, 89-96 (1954).

The production of a solid solution is considered to be the only practicable method of increasing surface hardness. Oxygen, carbon, hydrogen, boron and nitrogen were investigated by metallographic and microhardness studies. Heating titanium in both moist and dry air produced hardness values of up to 690 VPN, but scaling was excessive and brittleness resulted. Gas- and pack-carburizing produced rough, porous, loosely adherent surface layers and at temperatures >1400 F (760 C) brittleness occurred; hydrogen increased the surface hardness to 500 VPN, but surface cracking and brittleness were found at temperatures >1400 F. Electrolysis of titanium in molten borax at 1616 F (880 C) with a current density of 10 amp./dm.^{2} gave a rough surface with a shallow case of hardness 1000-1500 VPN. Heating titanium and several alloys in dry oxygen-free nitrogen produced a relatively hard, adherent case at 1500-1800 F (815-980 C). The properties are considered adequate for a commercial process; the best treatment consists of 16 hr. at 1600 F (870 C). Average surface hardness was 800 VPN; case depth was 0.0024-0.0028-inch titanium-base vanadium and boron alloys develop optimum hard, adherent cases at 1200 F (650 C) in purified nitrogen, but no other alloys yielded case properties superior to those of unalloyed Ti. Hardening in NH_3 is briefly mentioned.—MA. 9187

6.3.15, 5.4.2

Development of a Protective Coating for Titanium Alloys. Final Report (for) June 1, 1953 Through May 31, 1954. STANLEY KLUZ AND RALPH WEHRMANN. Fansteel Metallurgical Corp. (Contract DA-11-022-ORD-1069.) August 25, 1954, 40 pp.

The investigation of silicon as a coating material for titanium was continued. Paint and sinter, vapor phase and flame spray methods were studied. Coatings prepared

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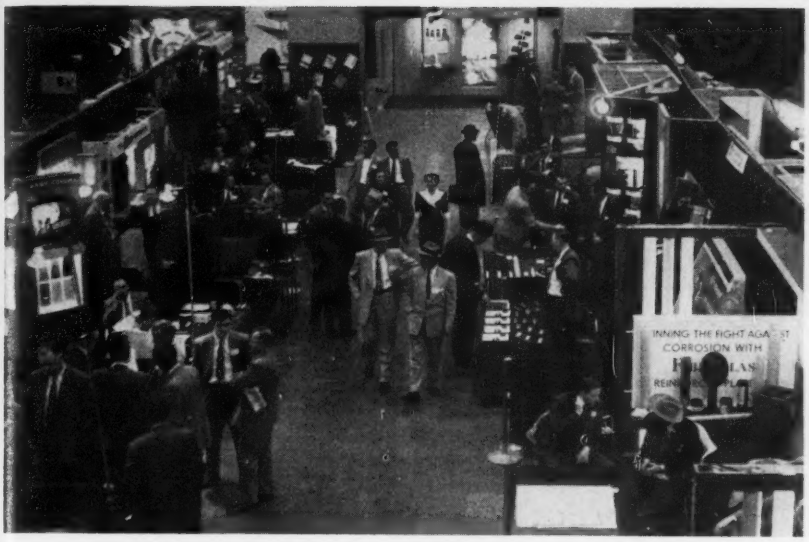

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by the first method increased the life span of titanium in air at 800 C by as much as a hundredfold. Cursory investigations of the last two methods indicated potential usefulness, particularly for some specific applications. Further study of silicon coatings should prove profitable. Titanium silicide powders were consolidated into pellets and bars by pressing at room temperature and sintering in vacuum. The silicides, Ti_5Si_3 and $TiSi_2$, are hard but reasonably strong intermetallic compounds which have very good oxidation resistance and relatively low electrical resistance. Crucibles of Ti_5Si_3 composition proved unsuitable as containers for melting titanium due to contamination with silicon which rendered the metal hard and brittle. (auth). —NSA. 9163

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2, 1.6

Rod, Bar and Wire Product Information. Book, 1954, 160 pp. Kaiser Aluminum and Chemical Sales, Inc., 919 N. Michigan, Chicago, Illinois. (Free if requested on company letterhead; otherwise, $2.00).

Comprehensive information on aluminum rod, bar and wire and their many applications is presented in the book. The publication is designed to assist engineers, designers, production personnel and purchasing executives in the selection and specific use of the most suitable aluminum rod, bar and die wire for different applications.

Production of aluminum, specific properties including corrosion resistance and characteristics as related to rod, bar and wire, new data regarding various alloys, their applications, fabrication and finishing methods are given. Illustrations showing many operations are given in the book. All aluminum alloys are indicated by the four digit index system in accordance with the new alloy designation system for wrought aluminum as adopted by the Aluminum Association. Also included are a glossary of descriptive words and definitions and many helpful engineering tables. 9117

6.4.2, 3.7.1, 3.2.2

Grain Boundary Attack on Aluminum in Hydrochloric Acid and Sodium Hydroxide. Disc. of E. C. W. PERRYMAN's paper by M. METZGER AND J. INTRATER. *J. Metals* (Trans. AIME), **6**, No. 5, 661-663 (1954) May.

M. Metzger and J. Intrater have carried out somewhat similar studies on the intergranular corrosion of high purity aluminum in hydrochloric acid which involved comparisons of aluminum containing 0.0004, 0.004 and 0.023% iron, in each case with 0.002% copper and 0.0001% silicon. They concluded that iron atoms segregate to the grain boundaries and affect the rate of intergranular attack, as was found by Mr. Perryman. However, the effect on the intergranular corrosion rate was not in the same direction with 7% hydrochloric acid. Using 7% acid the rate of intergranular penetration was only of the order of 10 microns per month and there is no continual evolution of hydrogen bubbles and the film forming over the grain surfaces was more substantial as shown by electron diffraction in other evidence. For specimens quenched from 647 C and exposed to 7% acid the intergranular attack was greatest for the aluminum of the highest iron content, in agreement with the behavior found by Mr. Perryman. The results suggest that the intergranular attack would not be absent even in ideally pure material and thus suggest that a concentration of impurity atoms in the grain boundaries is not the only factor responsible for susceptibility to intergranular attack in this acid. In Mr. Perryman's reply he states that in material with a low iron content, the excess concentration of iron at the grain boundaries will cause them to have a lower hydrogen overvoltage than the grains and hydrogen will be evolved from the boundaries and rapid grain boundary attack will take place. If the iron content is increased the hydrogen overvoltage will be the same at the grain boundaries and the grains and so more rapid general corrosion would be expected but the tendency to grain boundary attack would be decreased.—ALL. 9205

6.4.2, 3.7.3, 3.7.2

A Study on Aluminum-10% Magnesium Casting Alloy. Part III. MASAO KATO AND YASHUJI NAKAMURA. *Light Metals* (Japan), No. 11, 55-57 (1954) June.

The resistance to corrosion of aluminum-10% magnesium alloy, the effect of silicon and the difference of effects by both heat treatment processes according to JIS and DTD specifications were examined. 1) With the ordinary statical corrosion test, there was little difference of corrosion resistivity of any specimen. 2) In the stress corrosion test, silicon seemed to have little effect, while heat treatment processes had appreciable effect that is, the specimen according to DTD

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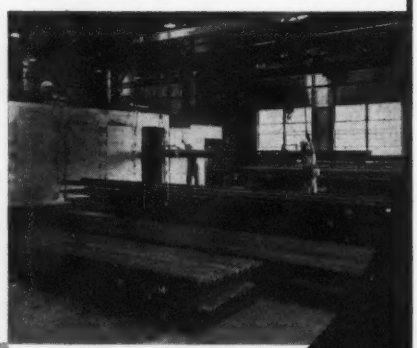

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specification is more sensitive to stress corrosion.—ALL. 9119

6.4.2, 4.4.5, 3.8.4

Mechanism of Reaction of Aluminum and Aluminum Alloys with Carbon Tetrachloride. Disc. of paper of MILTON STERN AND HERBERT H. UHLIG by H. G. OSWIN, W. W. SMELTZER AND M. J. PRYOR. *J. Electrochem. Soc.*, **101**, No. 6, 337-338 (1954) June.

In answer to a question concerning the organic end products of the reaction between aluminum and aluminum chloride, the authors state that a complex residue of by-products was found and also that no measurable quantities of chlorine were evolved during the reaction. In answer to W. W. Smeltzer, the authors state that heating the oxide film on aluminum causes some structural changes including recrystallization and perhaps the production of cracks. However, these changes did not explain decrease of the induction period after vacuum treatment. Increase in thickness of oxide films on heating does not balance any supposed loss of protection through structural change because anodized films equal to or thicker than the oxide films produced by heating are also not very effective in extending the induction period. Since natural oxide films on aluminum contain water and perhaps oxygen, both of which are removed by vacuum treatment, it is more likely that these factors account for the observations rather than a mechanism based on cracking of the film. M. J. Pryor states that if the interaction of aluminum and carbon tetrachloride proceeds by a free radical mechanism, then it should be possible to initiate the reaction by photolysis. The authors answer that they should be considerable effect of radiation on the reaction and that although they excluded light from the reaction vessels in which their experiments were carried out, they made no systematic effort to determine the magnitude of the effect.—ALL. 9209

6.4.2, 5.2.1

On the Cathodic Protection of Metals in Sodium Chloride Solution. Part I. Aluminum. (In Japanese). GORO ITO. *J. Japan Inst. Metals*, **18**, No. 3, 181-184 (1954) March.

The mechanism of cathodic protection of copper-containing aluminum alloys in 3% sodium chloride solution has been studied, using a model corrosion cell with an aluminum/$CuAl_2$ couple in it. When an external potential is applied to the couple to provide cathodic protection, the corrosion current decreases in inverse ratio to the potential, but the current flowing from the liquid into the cathode ($CuAl_2$) remains constant until the corrosion current becomes zero. Thus the cathodic polarization curve is independent of the external current until the cathodic current increases to such an extent as to suppress corrosion of the anode. To assure complete protection, the cathodic current must be proportional to the cathode area, though the polarized potential of the couple remains constant. Similar experiments were carried out with a tin/zinc couple and a tin-8.1% zinc alloy. Satisfactory agreement was found between the results obtained with the model cells and those with alloys in practice.—MA. 9106

6.4.2, 5.9.4

Corrosion-Protection of Aluminium by Natural or Intensified Oxide Films: Recent Investigations. (In German). D.

Why risk failure of a well engineered cathodic protection system by using inferior materials?

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ALTENPOHL. *Metall,* **9,** No. 5-6, 164-171 (1955) March.

The mechanism of oxide film formation is studied by investigating its correlation with the electrolytic potential of aluminum. Properties of the different oxide films are reviewed and it is found that the empirical data are in good agreement with the theoretical results obtained by the author.—ALL. 9216

6.4.2, 5.9.4

Corrosion Protection of Pure Aluminum, Raffinal and Some Corrosion-Resistant Alloys With Layers of Boehmite. (In German). D. ALTENPOHL. *Aluminium,* **31,** No. 1, 10-14 (1955) January.

Boiling water or steam treatments give coatings with protection value between atmospheric oxidation and anodizing. Graph, table, micrographs. 15 references.—BTR. 9226

6.4.4, 3.7.2

Tests on Magnesium-Zirconium Alloy Castings. *Aircraft Eng.,* **26,** No. 303, 162-163, 167 (1954) May.

Magnesium-zirconium alloys, studied by Dowty Fuel Systems Ltd. for use in aircraft, in general are very light (sp. gr. ~1.8), but their physical properties are rather low and they are subject to corrosion. Improved mechanical properties and corrosion resistance are gained by addition of zirconium. To assess the suitability of sand-cast ZRE 1 alloy a series of tests were carried out to check strength and freedom from porosity. A number of bores were made so as to provide conditions similar to those in a functioning production unit and porosity and strength checked by static pressure and pulsation tests. Thread shear tests and tests on the use of circlips to retain plugs in the bores were also carried out. The results of the tests showed that the properties of the cast material proved satisfactory and there was complete freedom from porosity. The thread tests showed that it should be possible to use standard threads and unions in connection with the material. The use of circlips for retaining plugs showed possibilities for the future. Tests on corrosion resistance against diesel-oil, kerosene, petrol or condensed moisture both in operation and under storage conditions are still in progress.—ALL. 9247

6.4.4, 5.9.4

The Behaviour of Magnesium in Alkaline Solutions. (In Russian). E. I. LEVITINA. *J. General Chemistry, USSR* (Zhur. Obshchei Khim.), No. 24, 216-218 (1954); *Chem. Absts.,* **48,** No. 18, 10407 (1954) Sept. 25.

Compact, protective films (exhibiting interference colors) were observed to form in concentrated alkali solutions with vigorous evolution of hydrogen. Cylindrical specimens of 99.96% magnesium (30 sq. cm. area) were exposed to solutions containing 810 and 1065 g/l of sodium hydroxide at temperatures of 20, 105, 120, 135, and 145 C. The films were removed by a 30 sec. dip in 20% chromic acid at room temperature. The weight gains (error not exceeding 10%) were measured up to one hour and followed a parabolic law, increasing with temperature and to a lesser degree with concentration of sodium hydroxide. Approximately one-half the reacted metal was dissolved. Changes in speed of stirring and the presence of oxidizing agents did not affect the rate of film growth. Reflection diffraction indicated magnesium oxide hydrate (simple hexagonal lattice, $a = 3.13$ $c = 4.75$ A.) which transformed to cubic magnesium oxide ($a = 4.20$ A.) on heating in air. Protective films approximately 2μ in thickness can be obtained by using 700-800 g/l of sodium hydroxide at the boiling point (130-135 C). More concentrated solutions produced a friable layer overlying the compact film.—ALL. 9153

6.4.4, 8.9.1

Elektron Magnesium and Elektron Magnesium-Zirconium Alloys for Aircraft and Aero-Engines. L. LASCH. *J. Soc. Licensed Aircraft Engineers,* March, 1954 (reprint), 11 pp. Obtainable from Magnesium Elektron Ltd., Bath House, 82 Piccadilly, London, W. 1.

A useful up-to-date summary. Development of these alloys; compositions, specifications, mechanical properties (tensile, compressive, fatigue, impact, hardness) in various conditions; creep properties; applications; corrosion prevention.—BNF. 9175

6.5 Metals—Multiple or Combined

6.5, 8.9.2

Powdered Metal Parts Find Increasing Automotive Applications. D. B. MARTIN. Chrysler Corp. *Machinery,* **61,** No. 3, 192-197 (1954) Nov.

Developments in powdered metal materials by Amplex Division of Chrysler are discussed. Oilite Bronze (90% copper-10% tin) is a self-lubricating bearing material, contains 25% oil by volume and is produced in a wide range of bearings, cored, bar and plate stock and finished machine parts. Other materials include: Super-Oilite (for high pressure applications); Super-Oilite 16 (for extreme pressure applications at low velocities); Iron Oilite (resistant to chemical and corrosive actions); Oilite Silver (copper-base, nickel-zinc alloy highly resistant to corrosion); and Oilite Stainless Steel (Type 302 alloy). Applications of these powdered metals in the automotive field include gasoline tank filter, engine bushing, oil pump gear in automatic transmission, shock absorber piston and coupling for hydraulic power steering. Production techniques employed are presented. Illustrations.—INCO. 8661.

6.5, 5.3.4

Powder Metallurgy. *Iron Age,* **174,** No. 14, 73-95, 98, 101-102 (1954) Sept. 30.

A collection of papers on various aspects of powder metallurgy including: Powder Metallurgy Can Lower Your Production Costs, B. T. Duport (pp. 74-75); Powder Press Design Keeps Pace with Industry Needs, J. L. Bonanno and R. B. Bouman (pp. 76-79); Hot Coining Produces True Density in Powder Metal Parts, G. J. Comstock (pp. 80-82); How to Get the Best Results from Sintering Furnaces, H. M. Webber (pp. 83-87); Proper Plating Techniques Give Good Surface Finishes, by H. H. Hausner and H. B. Michaelson (pp. 88-90); High Density Processing Widens Field for Powdered Metals, W. J. Doelker (pp. 91-93); and Case Histories of (Some Special) Powdered Metal Parts (pp. 94-95, 98, 101-102).—BNF. 9115

6.6 Non-Metallic Materials

6.6.6, 8.8.3

Glass Pipe and Fittings. G. F. GURNHAM. *Products Finishing,* **19,** No. 1, 58, 60, 64, 68, 70, 72 (1954) October.

Use of glass pipe and fittings in the plating industry is discussed. Glass developed specifically for corrosion resistance will withstand attack by nearly all acids and alkalies and by salts and organic substances at all reasonable temperatures. Reference is made to a paper by J. S. Chowning in which he describes the progress in the manufacture and use of glass piping.—INCO. 8468

6.6.7, 1.6, 5.4.3

What Every Engineer Should Know About Rubber. W. J. S. MAUNTON. Book, 128 pp. 1954. British Rubber Development Board, Market Buildings, Mark Lane, E. C. 3, England.

This book discusses the agricultural aspects of rubber, engineering applications, properties, rubber technology, uses of rubber in engineering, and under a heading "Resistance to Corrosion and Chemical Attack," says in part, "The outstanding resistance of rubber, which is a hydrocarbon (and therefore chemically inert) to attack by chemicals other than solvents, oxidizing and halogenating agents, has led to its wide use in lining chemical plant." Details of uses in lining vessels are given. There is an alphabetical subject index. 8741

6.6.8

Fluorine-Containing Polymers. J. GADSBY. *Trans. Plastics Inst.* (London), **22,** No. 47, 5-22 (1954).

The composition, preparation, structure, methods of fabrication, properties and range of usefulness of polytetrafluoroethylene and polytrifluoromonochloroethylene are described, compared and contrasted. The properties in both cases are related to the molecular structure.—RPI. 8550

6.6.8

Oil Field Structure Plastics Test Data are Given. Activity Report of NACE Technical Unit Committee T-1G on Oil Field Structural Plastics. *Corrosion* (News Section), **10,** No. 7, 17-24 (1954) July.

Data given on laboratory testing of glass plastic laminates, creep tests, tensile and bursting strength tests and temperature and combined load tests. Data accompanied by charts and illustrations of test equipment used. 8466

6.6.8, 4.2.3

Corrosive Fume Exhaustion Equipment. *Metallurgia,* **49,** No. 293, 142 (1954) Mar.

New Centrifugal fans and ductings are almost entirely constructed of rigid plastic industrial sheet, Vybak VR. 215, based upon polyvinyl chloride, and recently introduced by the Bolton firm of Turner & Brown Ltd. Material has high impact and tensile strength, good dimensional stability and exceptional resistance to chemical attack or weathering.—INCO. 8729

6.6.8, 7.2, 2.2.3, 8.4.3

Service Reports Given on Oil Field Plastic Pipe. Activity Report of NACE Technical Unit Committee T-1G on Oil Field Structural Plastics. *Corrosion,* **10,** No. 9, 9-16 (1954) Sept. (News Section).

Field service reports on 110,000 feet of plastic pipe in oil field service compiled by Technical Unit Committee T-1G. The data was taken from replies to a questionnaire circulated among operators of 73 installations embodying pipe from two to four inches in size and including polyvinyl chloride, sty-

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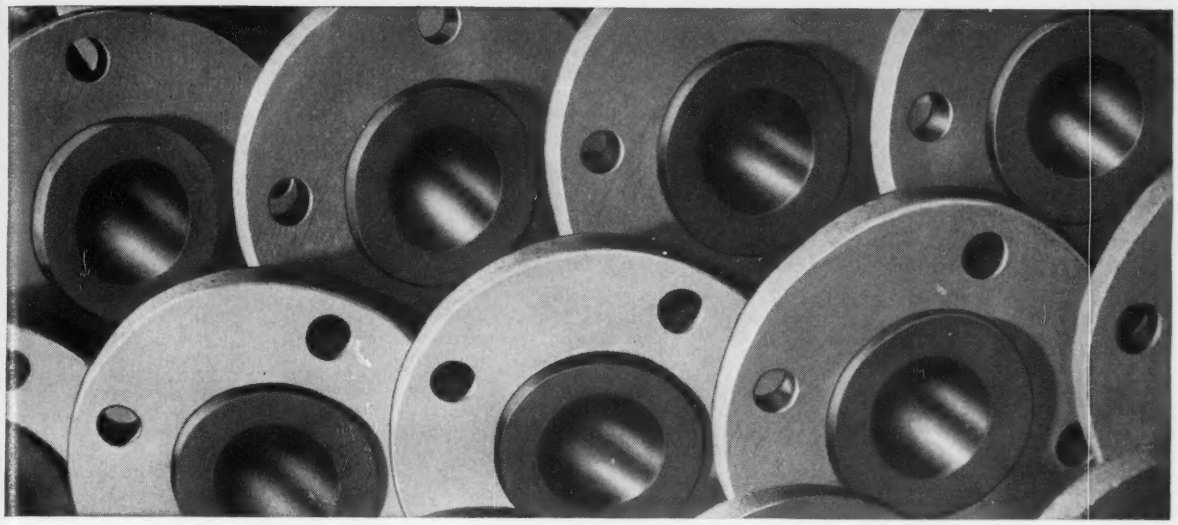

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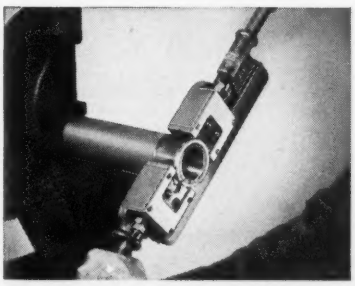

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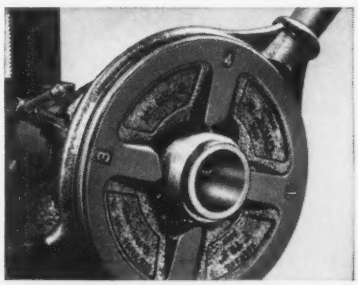
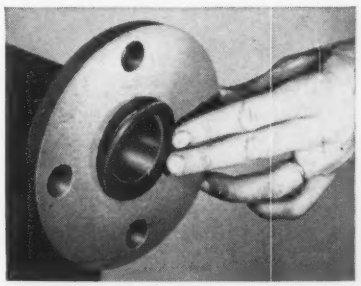


A ratchet type thread cutter makes the standard threads after the Beaver Cutter has been used. A flange or union fitting is attached and tightened until the liner is flush with the fitting.



If two flanges, or a union fitting, are used to make a pipe connection then a full gasket is required. If a flange is made up against a flange fitting or spacer then a half gasket is required.

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Twenty-four of the 73 installations experienced one or more failures, the largest number occurring during the first few days of operation. 8465

6.7 Duplex Materials

6.7.2.

New Refractory Hard Metals. J. L. EVERHART. *Materials & Methods,* **40,** No. 2, 90-92 (1954) August.

Physical properties, mechanical properties at high temperatures, oxidation and corrosion behavior of borides of zirconium, chromium and molybdenum and of nickel aluminide.—BNF. 8530

6.7.2

Carbides: Advantages and Limitations. C. H. GOOD. *Machinery,* **85,** 573-575 (1954) September 10.

Applications of carbides in machining Inconel X, titanium and ferrous materials; design of tools and optimum speeds. —BNF. 9246

7. EQUIPMENT

7.1 Engines, Bearings and Turbines

7.1, 4.4.7

Engine Bearing Design Today. J. B. BIDWELL. General Motors Corp. Paper before Am. Soc. Lubrication Engrs., 9th Ann. Mtg., Cincinnati, April 6, 1954. *Lubrication Eng.,* **10,** No. 5, 272-281 (1954) Sept.-Oct.

Discussion of problems peculiar to engine bearings as a consequence of operating conditions encountered. Corrosion of bearing materials by oxidation products of the lubricant has been reduced by development of corrosion-resistant bearing alloys, use of oxidation inhibitors in the oil and addition of detergents to oil which keep finely divided material in suspension and prevent deposition on engine parts. Sulfur, as an oil additive, may attack silver and copper bearing materials, though zinc bronze and aluminum bronze alloys possess resistance to this corrosive damage. Copper-lead bearings are especially sensitive to corrosion fatigue. Use of a lead-tin overplate increases life under the same operating conditions.—INCO. 8565

7.1, 4.7

Basic Information on the Bearing Properties of Various Materials in Liquid Metals. W. J. GREENERT AND M. R. GROSS. Naval Engineering Experiment Station, Annapolis, EES-090014B, July 2, 1954, 23 pp.

The report deals with the operation of aluminum thrust and journal bearings in NaK at ambient temperatures of 80 to 400 F. The thrust bearings, at 75-lb. load, showed little wear or deterioration after 11,000 hr. of exposure and intermittent operation in contaminated NaK. The journal bearings failed at these conditions under 20-lb. load. (auth)—NSA. 8547

7.2 Valves, Pipes and Meters

7.2

Corrosion by Valve Packing. L. M. RASMUSSEN. *Corrosion,* **11,** No. 4, 25-30 (1955) April.

The result of observations in the investigation of valve stem pitting during storage after hydrostatic testing was that the presence of soluble corrosive agents in the asbestos braid and graphite lubricant were responsible for the condition. Various packing treatments, graphites, sacrificial elements and inhibitors were formulated or chosen and tests conducted at three locations using Type 416 stem material. Test results indicate that removal of soluble corrosive constituents, incorporation of inhibitors or sacrificial elements and careful selection of graphite dry lubricant in the packing manufacture are beneficial and necessary. 8711

7.2

Improved Stainless Steel Needle Valve. A. R. GLASGOW, JR. AND G. S. ROSS, SR. *Anal. Chem.,* **26,** No. 12, 2003-2004 (1954) December.

A disadvantage of the usual construction of noncorrosive valves, in which both the stem and body are made of stainless steel of the same hardness, is that in use the stem becomes scored on the needle cone by the seat and on the shaft by the steel bushing located below the packing. An improved stainless steel needle valve which eliminates these disadvantages by use of steels of two different hardnesses is described. The valve body is an 18-8 stainless steel and the valve stem a 440-C high-carbon stainless steel. The relative difference in hardness between valve stem and body was found to be about 50 Rockwell C units. Illustration.—INCO. 8513

7.2, 2.3.2, 2.4.2

Accelerated Tests Aid Valve Selection. J. BOLTON. Lukenheimer Co. *Chem. Eng.,* **61,** No. 11, 268, 270 (1954) Nov.

New corrosion testing equipment, developed by Lukenheimer Co., simulates actual plant conditions, making it possible to specify the most economical materials for valve construction. By combining corrosion-resistant Causul metal, recently introduced, as the valve body material with Monel or Type 316 stainless steel as the valve trim material, valves are used successfully in applications where extremely expensive valves would otherwise be required. Electric furnace-melted Causul metal is an austenitic cast iron containing 18-21% nickel, together with small percentages of chromium, molybdenum, and copper. Table.—INCO. 8484

7.2, 3.5.8

Minimizing Stress Corrosion Cracking of Cylinder Valves. M. SCHUSSLER. *Corrosion,* **11,** No. 3, 19-22 (1955) March.

This investigation covers the diagnosis of the cause of splitting of aluminum bronze bonnets on valves for cylinders for handling corrosive gases and the remedial steps taken to minimize the failures.

The splits in the bonnets were found to be due to stress corrosion cracking which was induced by excessive torque applied to the bonnet, by a design weakness in bonnet itself and by the presence of longitudinal stringers of eutectoid in the material.

Laboratory tests showed that design changes could be made to strengthen the bonnets and that the stringers could be eliminated by heat treatment. The combination of heat treated bonnets, along with controlling torque applied to the bonnet nuts, eliminated bonnet failures in the valves. Improvements in bonnet design were incorporated in a new design for valves.

7.2, 6.6.11

Now Lock-Stave Wood Carries Highly Corrosive Liquids. *Power,* **98,** No. 11, 109-111 (1954) Nov.

Wood pipes of creosote-treated Douglas fir have strength to resist pressure, last indefinitely without pitting, scaling or tuberculation, have high acid resistance and have resilience and flexibility to conform to natural curvatures common to river-bed installations. Pipe shown carries highly corrosive pulp-mill waste liquor to disposal area. Wooden pipeline at Ketchikan Pulp Co.'s mill in Alaska is main water-supply line, leading from water-supply source to water filtration plant without rust or corrosion contamination.—INCO. 8687

7.2, 8.8.1

Resistant Pipelines in the Chemical Industries. F. F. JARAY. *Corrosion Prevention & Control,* **1,** No. 3, 143-147 (1954) May.

Some of the alternate materials available in the field of pipes and pipelines, such as lead, copper, stainless steel and non-metallic materials, including glass, ceramic, asbestos-filled furane and phenolic resins, rigid PVC, cellulose acetate butyrate and hard rubber are discussed. Lined pipes, using rubber, soft and rigid PVC, polyvinylidene chloride and ceramics are considered.—INCO. 8548

7.4 Heat Exchangers

7.4.2, 6.4.2, 2.2.3

Aluminum Alloy Heat Exchangers in the Process Industries. W. W. BINGER AND H. W. FRITTS. *Corrosion,* **10,** No. 12, 425-431 (1954) December.

Laboratory tests to determine the suitability of metals for use as heat ex-

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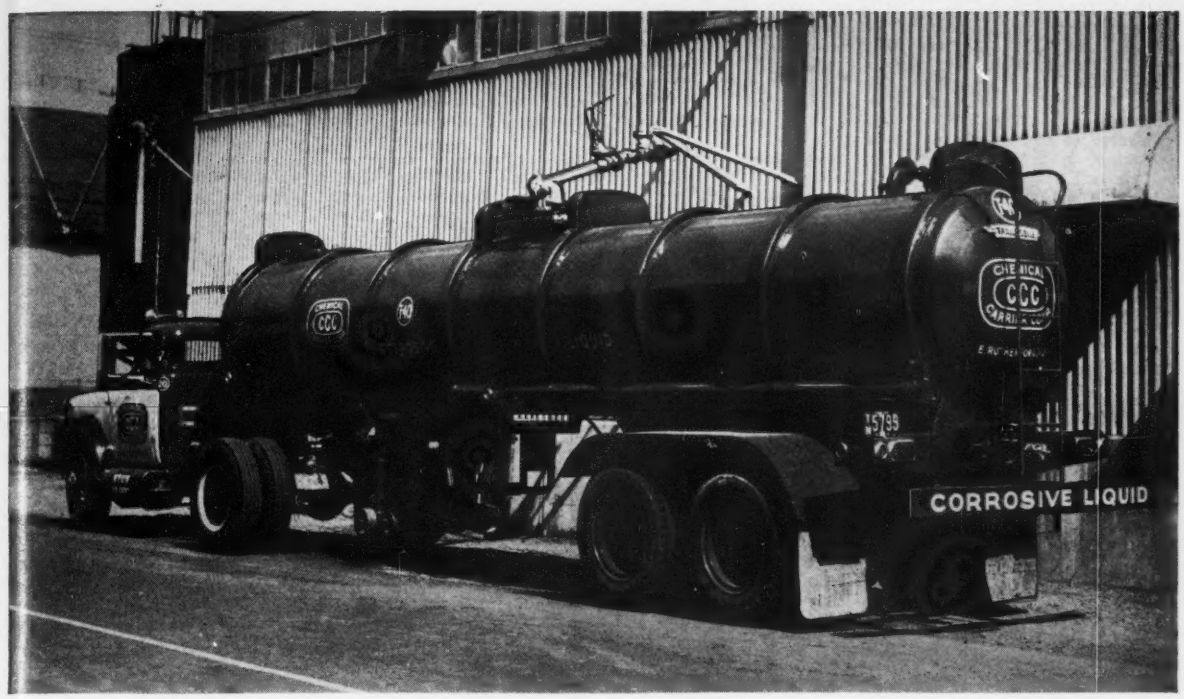

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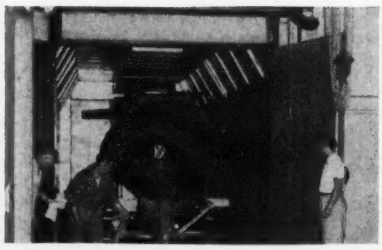
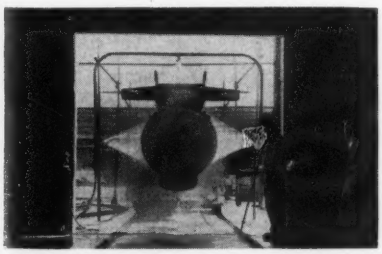


BAKE OVEN at Kellogg Plant, Jersey City, N. J. Overall length 85 ft., width 12 ft., height 12 ft., iso-thermal control, ±5°F. This new Kellogg oven is being used to develop improved techniques for large area applications.



QUENCHING—After final baking, tank is quenched to produce tough, transparent, flexible coating.

This tank, which is designed to transport corrosive chemicals without danger of contamination of the final product, was spray coated with KEL-F Dispersions at the Kellogg plant in Jersey City, and baked-fused in a specially built oven large enough to complete each coating in a single operation. Preliminary tests were carried out with a slightly smaller tank, and the correct techniques developed before proceeding with the coating operations on the tank truck.

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changer tubes under corrosive conditions should include temperature, ratio of metal area to solution volume, velocity, heat transfer and operating temperatures, pressure contaminants and other factors. For this reason it sometimes is necessary to test metals under service conditions to get an accurate estimate of their resistance.

Aluminum heat exchanger equipment has given excellent service in ammonia dephlegmators and condensers, with natural cooling waters with pH values of 4.5 to 8.5; with steam and in petroleum catalytic and thermal cracking processes including gasoline plant service, lubricating oil service and desulfurization. Aluminum tubes also have long service records handling distilled naphthenic acids, ethyl benzene, hydrogen peroxide, fuming nitric acid, vegetable oils, oxygen, urea and naval stores.

It has proved helpful to include inhibitors in certain applications. Investigations show that the rate of heat transfer as well as the direction of heat flow sometimes are important factors determining the rate of corrosion. Details of recommended construction are included. 8557

7.5 Containers

7.5.2, 5.4.8

Organic Protective Decorative Coatings for Metal Containers. T. G. Green and M. Thomas. Paper before Inst. Met. Finishing (Organic Finishing Group), London, Jan. 26, 1954. *Bull. Inst. Met. Finishing*, **4**, No. 3, 227-236; disc., 237-238 (1954) Autumn.

Application of protective lacquers and decorative organic coatings to sheet metal which is subsequently formed into containers. Lacquers for processed food cans are used to prevent interaction between the metal of the can and the contents by reducing the amount of exposed metal and must possess freedom from flavor, freedom from toxic materials and resistance to processing. Fruit acids will react with tin and some of the sulfur proteins in meats and vegetables may decompose during sterilization to lower molecular weight products which combine with tin and any iron which may be exposed on the inside of the can to form sulfides. Lacquers for fruits, vegetables, meat products, fish products and beer, including phenolic resin, vinyl resin and oleo-resinous (containing zinc oxide) lacquers are considered. Composition and general properties of sizes, decorative coatings and varnishes are discussed. Eight references.—INC. 8555

7.5.2, 8.3.5

Metal Containers for Food. J. G. Huntley. Paper before Soc. Chem. Ind., Food Group, So. Wales and Bristol Section, Nov. 25, 1954. *Chemistry & Industry*, No. 47, 1434-1437 (1954) Nov. 20.

Consideration of hermetically sealed cans, their manufacture and the conditions they must withstand during shelf life. History of metal containers for food is traced. At the end of the 1920's, to prevent corrosion of inside surface, cans for some products were coated with lacquer applied to the flat tinplate sheet and baked at high temperature. Major advance of 1930's was continuous cold reduction processing of steel base, making possible production of sheet steel with reduced impurities, if parting uniform corrosion resistance and reducing losses of canned fruits from hydrogen swells and perforations. Lacquers and lining compounds are discussed. Untinned steel and aluminum are protected either by a chemical filming treatment or application of an organic coating material. Concerning atmospheric corrosion, it was found that conditions of storage are more important than the actual thickness of the tin coating.—INCO. 8473

7.5.5

The Control of Vapor-Zone Corrosion in Sour-Crude Tanks. A. H. Newberg and J. P. Barrett. Paper before Am. Petroleum Inst., Ann. Mtg., Chicago, Nov. 9, 1954. *Petroleum Eng.*, **26**, No. 12, D22-D23, D25-D26 (1954); *Oil Gas J.*, **53**, No. 28, 189-192 (1954) Nov. 15.

Vapor-zone corrosion in sour-crude tanks can be controlled by design, use of resistant materials, inhibitors, or coatings, although no one method has proved completely successful. Corrosion in the vapor-zone is dependent upon hydrogen sulfide, oxygen and water and internal bottom corrosion is brought about by galvanic action between ferrous sulfide scale and the bottom of the tank. Although design is probably the most effective method to combat corrosive attack and considerable progress can be made in the field of inhibitors, application of organic coatings is the most widely used method of controlling vapor-zone corrosion. Criteria for determining effectiveness of coating systems, laboratory evaluation, application by spraying and other coating methods are discussed. Illustrations.—INCO. 8671

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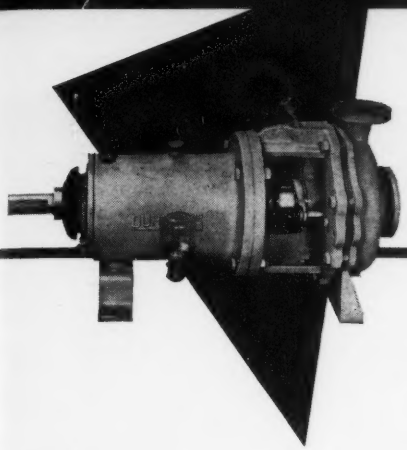

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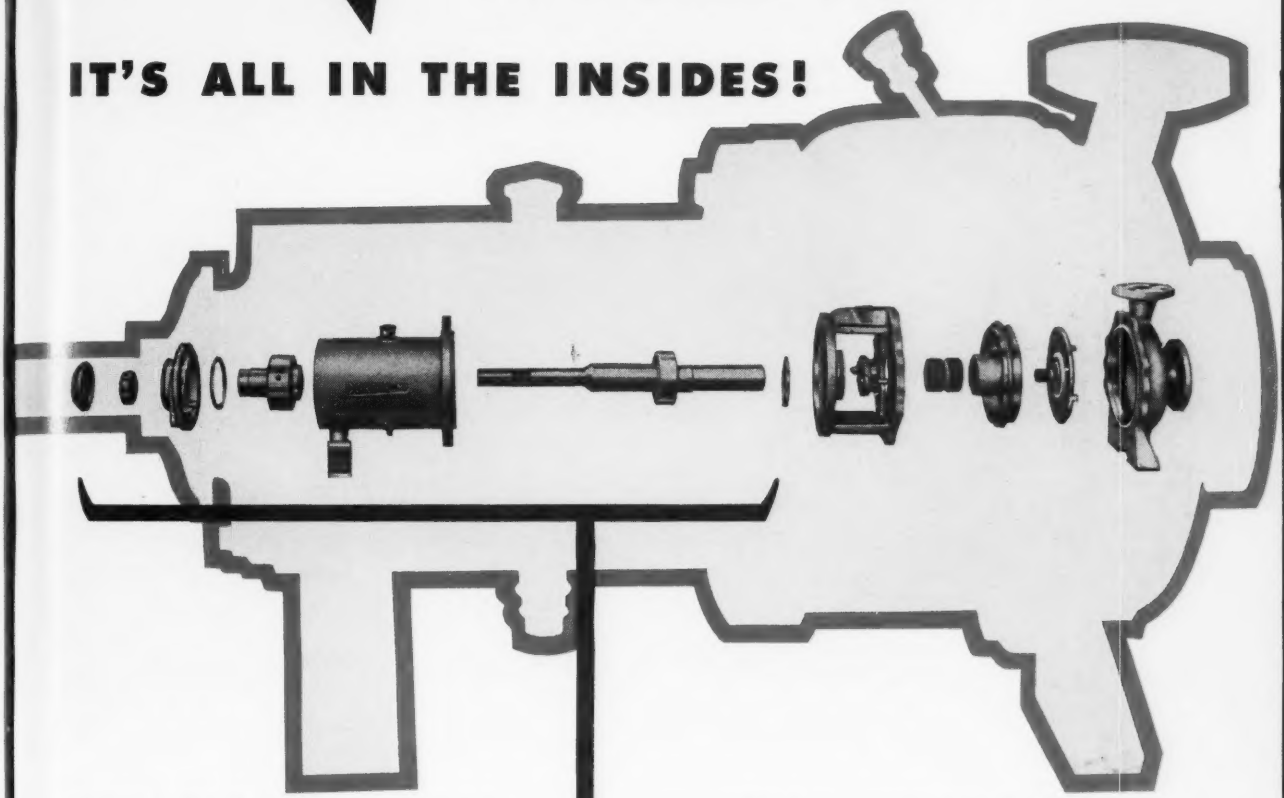

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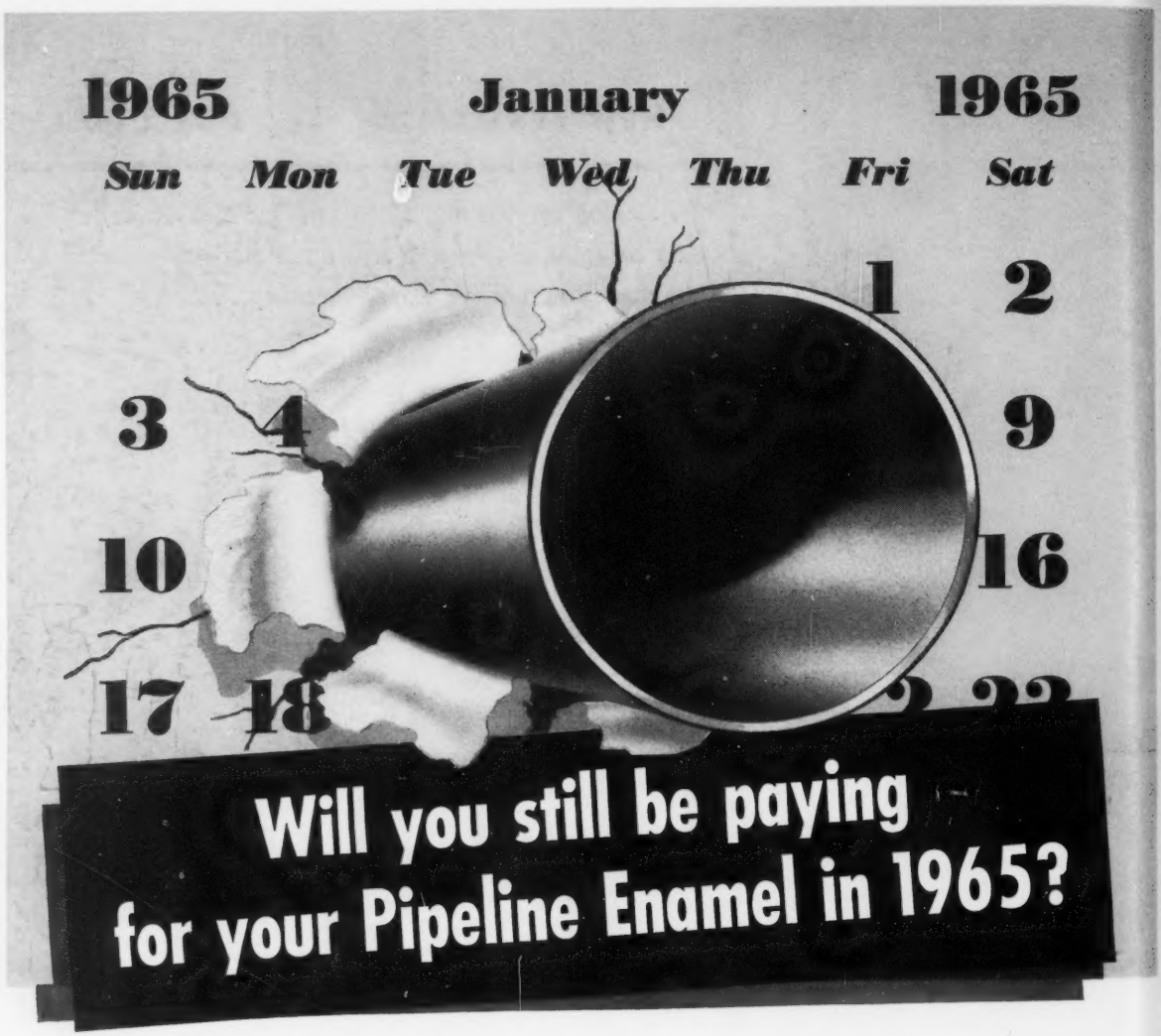

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